THE DESIGN CRITERIA OF NET-ZERO ENERGY SCHOOL UNDER MILD CLIMATIC CONDITION IN SAUDI ARABIA

BY

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To

my loved ones..

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LIST OF ABBREVIATIONS

AC	Air Conditioner
ACH	Air Changes per Hour
AIA	American Institute of Architects
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration and Air conditioning
ASTM	American Society for Testing and Materials
BIPV	Building Integrated Photovoltaic
BPS	Building Performance Simulation
BTU	British Thermal Unit
CFL	Compact Fluorescent Lamp
CLF	Cooling Load Factor
COP	Coefficient of Performance
db	Dry bulb, °F
DHW	Domestic Hot Water
DOE	Department of Energy (United States)
DX	Direct expansion
DXF	Drawing Exchange Format
EER	Energy Efficiency Ratio
EEV	Electronic expansion valves
EIA	Energy Information Agency
EUI	Energy use intensity
GSHP	Ground-source heat pump
GUI	Graphical User Interface
HDD	Heating Degree Days
HSPF	Heating season performance factor
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
ISO	International Organization for Standardization
KFUPM	King Fahd University of Petroleum & Minerals
kW	Kilowatt
LBNL	Lawrence Berkeley National Laboratory
LCC	Life Cycle Cost
LCS	Life Cycle Savings
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
LPD	Lighting power density, W/ft2
MOE	ministry of Education, SA
NASA	National Aeronautics and Space Administration
NEMA	National Electrical Manufacturers Association

NPV	Net Present Value
NREL	National Energy Renewable Laboratory
NZEB	Net Zero Energy Building
O&M	Operation and maintenance
OPR	Owner’s project requirements
PBP	Payback Period
PMV	Predictive Mean Vote
PV	Photovoltaics
R	Thermal resistance
RSHR	Room Sensible Heat Ratio
SEC	Saudi Electricity Company
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar heat gain coefficient
SHR	Sensible Heat Ratio
TMY2	Typical Meteorological Year 2
U	Thermal transmittance
USGBC	U. S. Green Building Council
VT	Visible transmittance, dimensionless
W	Watts
WSHP	Water-source heat pump
WWR	Window-to-Wall Area Ratio
AEDG	Advanced Energy Design Guide for K-12 School Buildings
ZEB	Zero energy building
ZES	Zero energy school

ABSTRACT

Full Name : Hasan Saeed Fardan

Thesis Title : The Design Criteria of Net-Zero Energy School Under Mild Climatic Condition in Saudi Arabia

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The main purpose of this thesis is to study, assess and demonstrate the technical and financial feasibility of net zero energy school building(NZEB) in the mild climatic condition in Saudi Arabia. To accomplish this goal, a detailed building energy performance of selected standard school buildings in the mild climatic condition in Saudi Arabia will be examined on a real case study. The energy performance analysis is to correctly find the buildings' energy needs in studied environments and finally propose retrofitting strategies about NZEB. The study will be established on a real case study of selected governmental schools, with typical reinforced concrete structures. The location of the case study is a highland region in southwestern Saudi Arabia. Starting from performing simulation scenarios of the existing school building, different proposed design settings will be considered and validated. Moreover, an economic analysis of proposed design settings will be investigated, in order to assess the technical and economic feasibility of a net zero energy school building.

ملخص الرسالة

الاسم الكامل: حسن سعيد فردان

عنوان الرسالة: معايير التصميم لمبنى مدرسي ذو استهلاك صفري للطاقة تحت ظروف مناخية معتدلة في المملكة العربية السعودية

التخصص: الهندسة المعمارية

تاريخ الدرجة العلمية: ابريل 2018

الهدف الرئيسي من هذه الرسالة هو دراسة وتقييم وإثبات الجدوى الفنية والمالية لمبنى مدرسي ذو استهلاك صفري للطاقة (NZEB) في الظروف المناخية المعتدلة في المملكة العربية السعودية. ولتحقيق هذا الهدف ، سيتم دراسة أداء مفصّل للطاقة في المباني المدرسية السائدة المبنية من هياكل خرسانية مسلحة في الظروف المناخية المعتدلة في المملكة العربية السعودية وسوف تتم الدراسة على حالة حقيقية من خلال تحليل أداء المبنى المدرسي من ناحية العوامل المؤثرة في استهلاك الطاقة في المناخات المعتدلة في في جنوب غرب المملكة العربية السعودية عن طريق اختبار سيناريوهات مختلفة لمبنى المدرسة الحالي باستخدام برامج كمبيوتر تحاكي الاداء الفعلي للمبنز سيتم النظر في إعدادات التصميم المقترحة المختلفة والتحقق من صحتها. وفي النهاية سيتم اقتراح استراتيجيات لرفع اداء المبنى وتحديث المواصفات لتحقيق الهدف وعلاوة على ذلك ، سيتم التحقيق في التحليل الاقتصادي لظروف التصميم المقترحة ، من أجل تقييم الجدوى الفنية والاقتصادية لبناء مدرسة ذات استهلاك صفري للطاقة.

CHAPTER 1

INTRODUCTION

1.1 Background

Saudi Arabia is one of the fastest countries in population growth at an annual rate of 2.54%. Moreover, it has a total population of more than 31.7 million as shown in Figure1.1 [7], and accordingly the demand on energy has grown sharply.

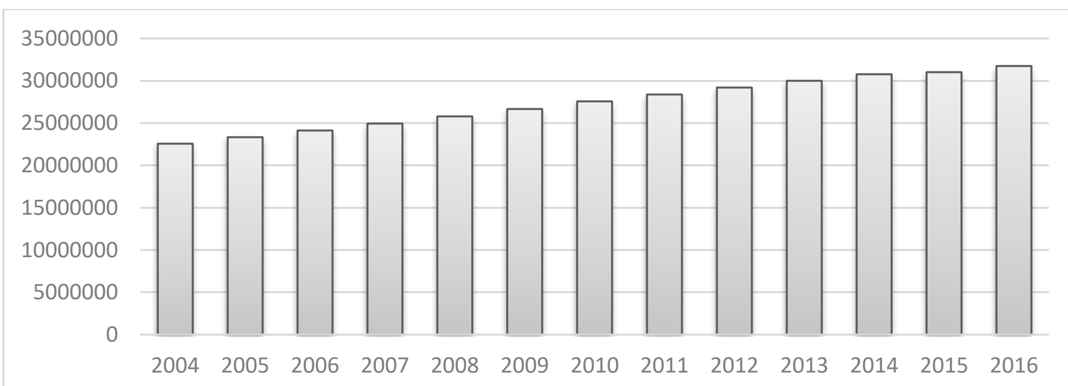


Figure 1. 1 Population Growth in Saudi Arabia

Most of the Kingdom's growth in the energy consumption is pushed mainly by the needs of the growing population, rapid increase in construction segment, high demand for air conditioning in the summer season, and low consumer tariff, as shown in Figure1.2 [14].

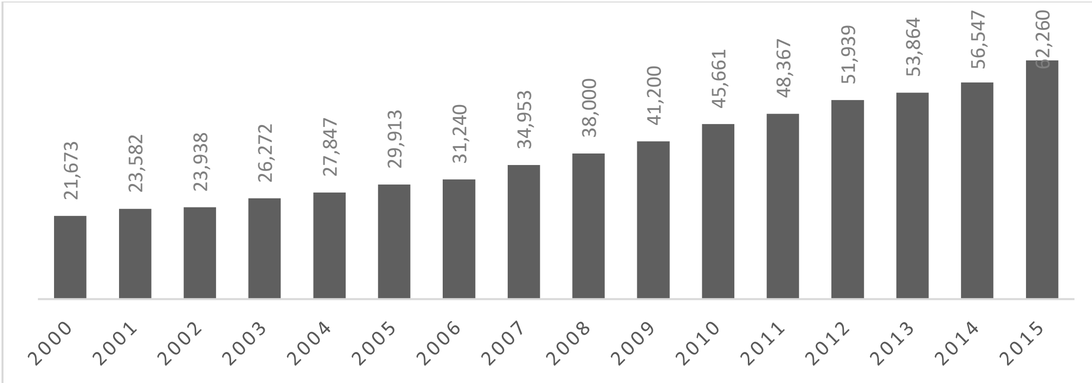


Figure 1. 2 Development of Peak Load (MW) during (2000-2015) [12]

According to a recent available data by the Electricity and Cogeneration Regulatory Authority [14]Saudi Arabia is totally depending on fossil fuels to generate electricity, with a natural gas and oil supply of 50% of share for both. The usage of renewable-based sources is absent and has no contribution to the national grid Figure1.3.

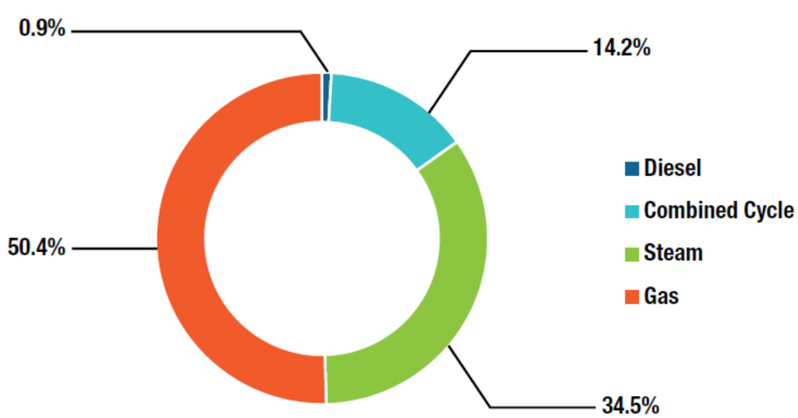


Figure 1. 3 Electricity Generation Fuel Mix in KSA (2014) [14]

Buildings in Saudi Arabia (SA) that include the residential, governmental and commercial sectors consume about 80% of the total electric energy consumption in the Kingdom Figure1.4 [14].

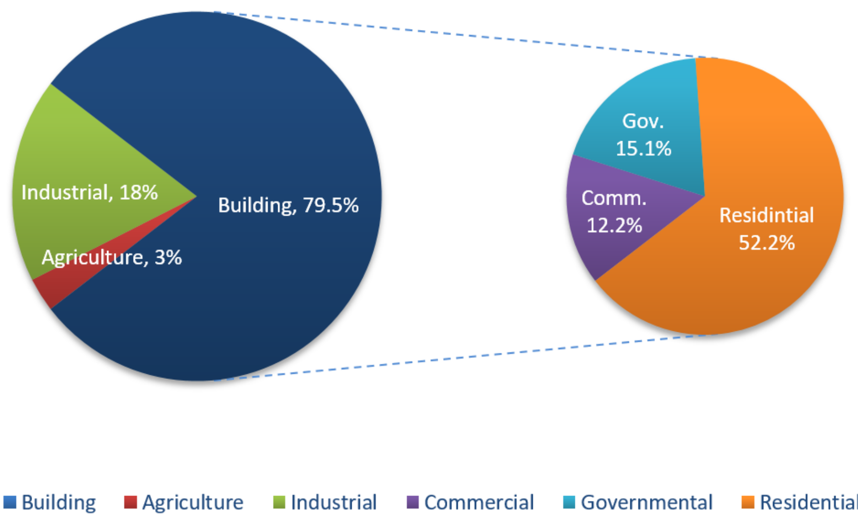


Figure 1. 4 Energy shares by Consumption Types

Worldwide, a considerable number of programs to improve building energy efficiency has been implemented. The US Department of Energy has a program called Energy Smart Schools. This program includes the following: increase the user's awareness, conduct workshops, issue publications, technical support and funding opportunities, so as to develop school buildings' energy efficiency and finally, measure the improvement of thermal performance for the envelop or the upgrade of passive ventilation design which are popular in today's practices [11]. The California Energy Commission Program provides services to support the public to refurbish and construct new green schools [5]. The Future Building Schools is a United Kingdom program to increase the energy efficiency in the school buildings [10]. The program develops guidelines for new educational buildings as well as a framework for sustainable improvement for existing school buildings.

Improving building energy efficiencies on demand side will have great impact on economic and environmental aspects. Recently, the concept of Net- Zero Energy Building (NZEB) has attracted global interest and has led to the beginning of a new generation of buildings. They are defined as the buildings which, produce as much energy as it consumes, usually on an annual basis.

Different governmental agencies and organizations in Saudi Arabia in union with Saudi Energy Efficiency Center (SEEC – created 2010), developed a promising program called, the Saudi Energy Efficiency (SEEP) in 2012. The aims of this program are to reduce the energy demand by about 33% until 2030 and to cut half of the peak load growth by 2015. The program includes strategies to diversify the energy supply side by the utilization of renewable energy from one hand and increasing demand side energy efficiencies on the other hand.

1.2 Statement of the Research Problem

The educational sector in SA is the second largest governmental sector in terms of customer numbers (National Energy Efficiency Program- Final Report; Objective 2- Energy Efficiency Information and Awareness, Volume 2A). The annual cost of electricity bill of public school is 7.2 billion SR, comprising 20% of total government electricity consumption (Ministry of Education). Therefore, this thesis will address the strategies to achieve the design to reach Net Zero Energy Building(NZEB) for schools in mild climatic conditions in SA. This research involves energy performance assessment to find out possible passive, active and renewable design strategies for Net-Zero Energy Schools and to perform an economic assessment.

1.3 Significance of the Research

Bringing down the power consumption in SA through the adaption of energy conservation actions on the demand side is essential for sustainable future. The application of NZEB concept will help significantly in achieving this goal and it will contribute to achieve SA's 2030 vision. This research will highlight the design criteria of NZEB of public school including Energy Conservation Measures (ECMs) and Solar Energy Utilization to cover the school's need of power.

1.4 Research Objective

The main objective of the research is to study the strategies and design criteria that cauld be applied to the existing school design and will achieve the goal of net-zero energy buildings (NZEB) at reasonable cost increment in mild climate areas in Saudi Arabia (SA)

1.5 Scope and Limitations

The thesis has the following limitations:

- The measures that will be used in this study will focus on school buildings under mild climates in SA.
- The strategies that will be used in this model are limited to the current school design and targeting the future school buildings.

- This study will consider the Energy Conservation Measures(ECMs) focused on improving the existing design and systems to the most possible level.
- No major modifications will be applied to the form and walls structure

1.6 Research Methodology

This study contains three parts. In the first part, a comprehensive literature review is presented, showing the related studies locally and globally to find out the best practices in the field of high performance and Zero Energy Building and the current practices of NZEB. This literature review presents the benefits and weaknesses of NZEB through the study of life cycle costing.

The second part assesses the opportunity of achieving an NZEB school building through a case study with consideration of alternatives of passive, active renewable energy systems, energy efficiency, cost effectiveness and user comfort. The third part performs an analysis of cost-effectiveness of alternatives of passive, active and renewable energy systems to find out the best design variables. Figure1.5 demonstrates the research approach to reach the NZEB school building.

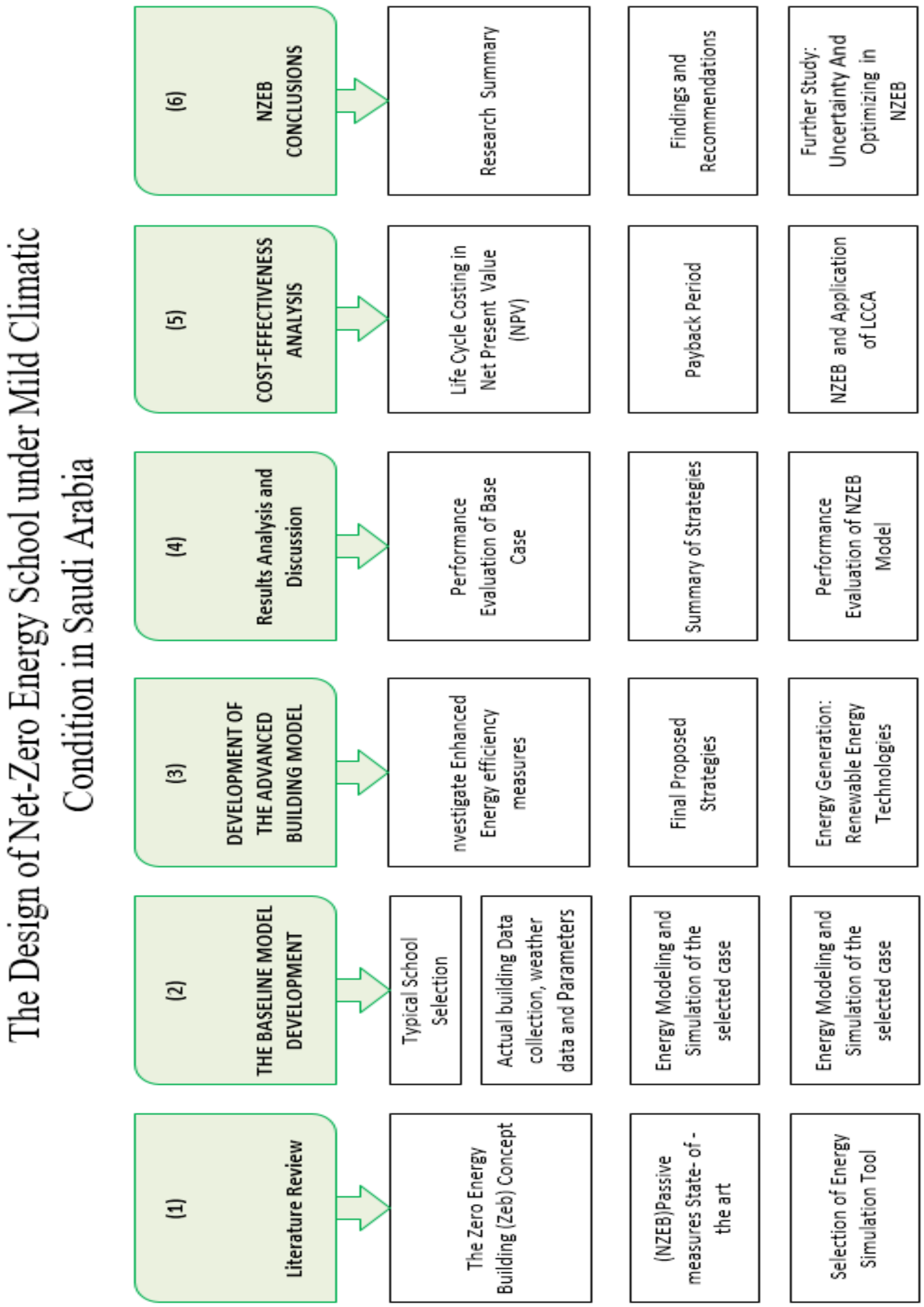


Figure 1. 5 Research Methodology

Chapter 2

LITERATURE REVIEW

2.1 Building sustainability, Standards and Rating systems

A sustainable (Green) building is a major factor in the sustainability development and it has directed the attention towards rapid improvements in policies, rules and regulations around the globe looking for more efforts to implement sustainable strategies in terms of products and procedures to encourage more green buildings[44]. A clear definition of sustainability is this: “Sustainability development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (The Brundtland Commission, 1987) Figure2.1. Sustainable (Green) buildings are described as buildings that incorporate standards for benefit of environment, society and economy standards[41].

Figure 2. 1Sustainability Three Pillars

Sustainability awareness has evolved and in the current business trends, energy demand in buildings is just one factor among other factors where the complications of a building often implies an approach with multi-disciplinary in sustainability evaluation. Thus, the building sustainability should be assessed for every subcomponent (e.g. HVAC systems, the windows, etc.) in addition to the whole building and its surrounding environment [28]. The green building area has the main energy conservation potential, yet without an assessment system, the credit of sustainable buildings will be uncertain [44]. Worldwide, many rating systems exist to evaluate building sustainability where some of them are just customized to one system with some adjustments according to the local area. The common building rating systems are LEED, BREEAM, CASBEE, Building Greenhouse Rating in Australian (ABGR), the United State Assessment and Rating System (STARS) and Green Globes as shown in Table 1.1 [25].

Table 2. 1 Common Building Rating Systems

Country	Rating System
Austria	Nabers/Green Star
Brazil	AQUA/LEED Brazil
Canada	LEED Canada/Green Globes
China	GBAs
Finland	PromisE
France	HQE
Germany	DGNB
Hong Kong	HKBEEM
India	GRIHA National Rating System developed by TERI/LEED India
Italy	Protocollo Itaca
Japan	CASBEE
Mexico	LEED Mexico
Netherlands	BREEAM Netherlands
New Zealand	Green Star NZ
Portugal	Lider A
Singapore	Green Mark
South Africa	Green Star SA
Spain	VERDE
U S	LEED/Living Building Challenge/Green Globes Build it Green
U K	BREEAM

BREEAM was the first building rating system for sustainability evaluation where it was established in the early 90s by the British Research Establishment (BRE) and then announced in 1993. It has a big implementation in the U.K., where it has certified nearly 10,000 buildings. Consequently, global versions of this system have been announced, and presently BREEAM has modified versions for Hong Kong, Australia, and Canada.

Another well-known building evaluation process is LEED (Leadership in Energy and Environmental Design). LEED was established in 1998 by the United State Green Building Council (USGBC) and it has spread around the world. Thousands of buildings are listed for LEED certifications in US, and in 110 other countries around the world.

2.1.1 LEED Green Certification

LEED is a system for certifying a building according to its compliance with sustainable requirements with consideration of environmental [34]. The LEED system at first, issues certification for new construction. In 2004 LEED has included the existing and commercial buildings. In 2007 shell and core certification was included.

Table 2. 2LEED Construction Certification V3 and V4

	Version 3.0		Version 4.0 - Draft	
Category	Credit Options	Points Possible	Credit Options	Points Possible
Sustainable Sites	15	26	7	10
Water Efficiency	4	10	7	11
Energy & Atmosphere	7	35	11	33
Material & Resources	10	14	7	13
Indoor Environmental Quality	17	15	11	16
Location & Transportation			8	16
Integrated Process			1	1
BONUS:				
Introduction/Other	2	6	2	6
Regional Priority	1	4	1	4
TOTAL	**56**	**110**	**55**	**110**

LEED is providing flexibility for making points in building certification in several categories as shown in Table 1. 2**.** The system is built on a point method, allowing members to achieve certification and choose between four ascendant levels; Bronze, Silver, Gold, and Platinum (www.usgbc.org), as listed in Table 2.3.

Table 2. 3 LEED- Levels by Version categories

Certification Level	V2.2	V2009	V4
Certified	26-32	40-49	40-49
Silver	33-38	50-59	50-59
Gold	39-51	60-79	60-79
Platinum	52-69	80 or above	80 or above

ASHRAE 55 standard provides adequate range of indoor conditions that are satisfactory to achieve thermal comfort for users. The ASHRAE adaptive model provides a relationship between operative temperature for indoor comfort and mean monthly outdoor

temperature for naturally ventilated spaces.

2.2 The Zero Energy Building (Zeb) Concept

The term net zero energy building is quite new, but the actual transition to low CO_2 emission and efficient energy buildings started with some passive measures in houses in the early part of 1920 [50]. MIT Solar Laboratory (built in 1939) is the first attempt to calculate the energy performance of solar collectors[13]. The general belief of that time was that the simple strategies would be effective, affordable, and friendly to the environment [11]. Utilization of renewable energy on houses started in the 1970s by building solar houses. The main disadvantages with the simple technology was the absence of appropriate control of different systems.

In 2007, Energy Independence and Security Act (EISA) developed the NZEB for Commercial buildings with certain goals including:

- In 2030 the buildings in new commercial sector must be designed and constructed in net zero energy goal.
- In 2040 half of commercial buildings in the USA must reach the net zero energy goal.
- In 2050 all commercial buildings in the USA must achieve the net zero energy goal.

2.3 Net Zero Energy Building Definitions

There are several definitions for a NZEB and each definition differs depending on the boundary and metric used to define the building. A NZEB is ideally a building that through high efficiency gains can meet the rest of its energy needs through renewable technologies. In simple terms, the net energy of a NZEB is the sum of the energy flowing equals the sum of the energy flowing out Figure 2.2. ASHRAE defines NZEB as “A building which, on an annual basis, uses no more energy than is provided by the building’s on-site renewable energy sources”. National Renewable Energy Laboratory (NREL) defines it as “A residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies”. The US Department of Energy (DOE) states: “A building that produces and exports at least as much emissions-free renewable energy as it imports and uses from emission-producing energy sources annually”

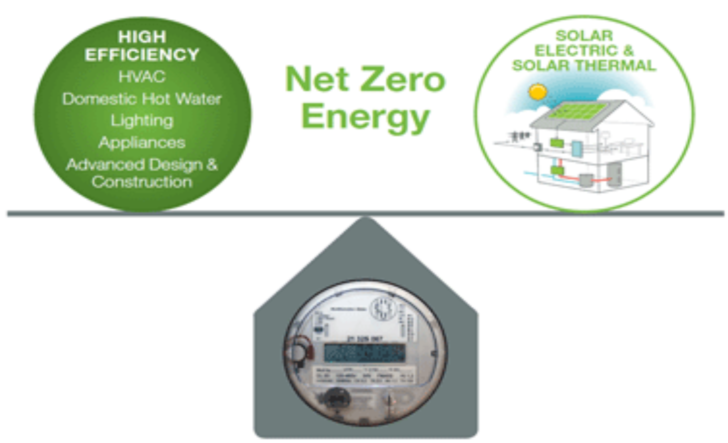


Figure 2. 2 NZEB is the energy flow[36]

The International Energy Agency (IEA) defines a NZEB as “a building that remains neutral over a year by getting all of its needed energy from the sun and other renewable sources instead of fossil fuels with delivering as much energy to the supply grid as using from the grid” [47].

The New Buildings Institute (NBI) characterized the Net-Zero Energy (NZE) Building as a structure that has a net energy flow of zero, that is, energy used equals energy produced. The energy mentioned here is energy from renewable sources Figure 2.3. The building uses energy in the form of electricity, gas, steam, liquid fuel, etc. The net energy flow also changes from time to time and is calculated as the average over the year. NBI also defines the equation:

$$A - B = C,$$

Where,

A = annual energy use in kBtu/sf/yr,

B = annual onsite renewable production in kBtu/sf/yr, and

C = Annual Net Energy Use Intensity in kBtu/sf/yr; kBtu stands for kilo British thermal units, sf for square feet and yr for year.

This equation is used to compute the projected (in the design phase) or actual net zero energy status of a building over a year. It is important to express all energy forms used and produced in the building in kBtu/sf/yr, so as to standardize all fuel and be able to compute for the Energy Use Intensity.

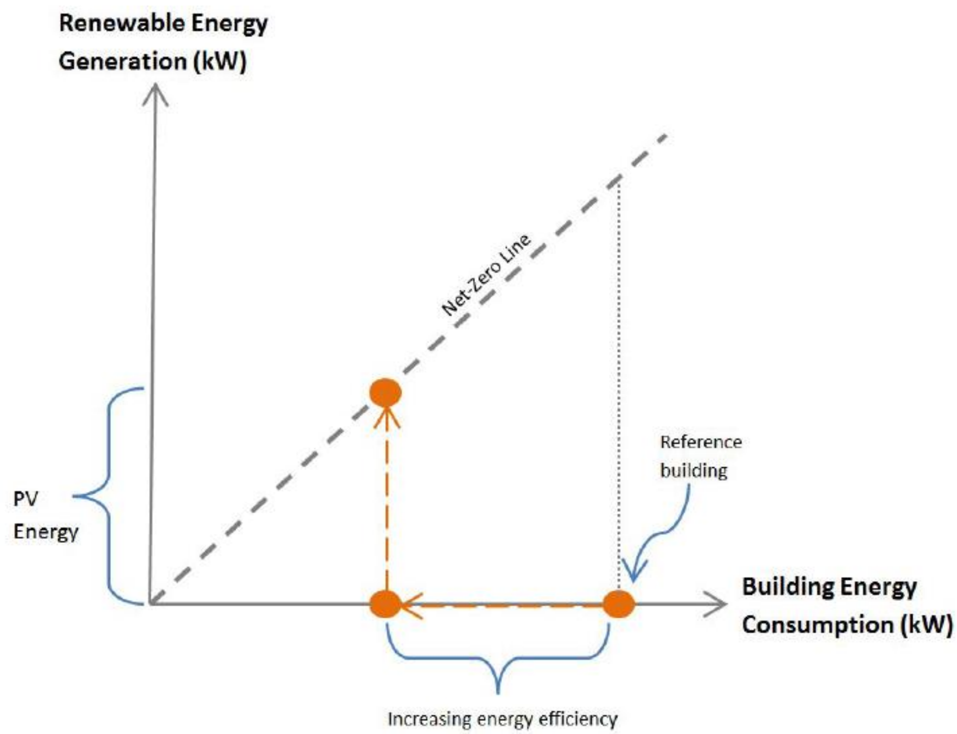


Figure 2. 3 Transition way to a Net Zero Energy Building

2.4 Guidelines to Design NZE Buildings

A study conducted by (Hutton 2011) illustrates the phases to achieve NZEB by firstly considering passive design strategies to decrease building energy use and then maximize the energy efficiency for the systems, then cover the remaining need of energy by utilizing the available renewable energy technologies Figure 2.4 [23].

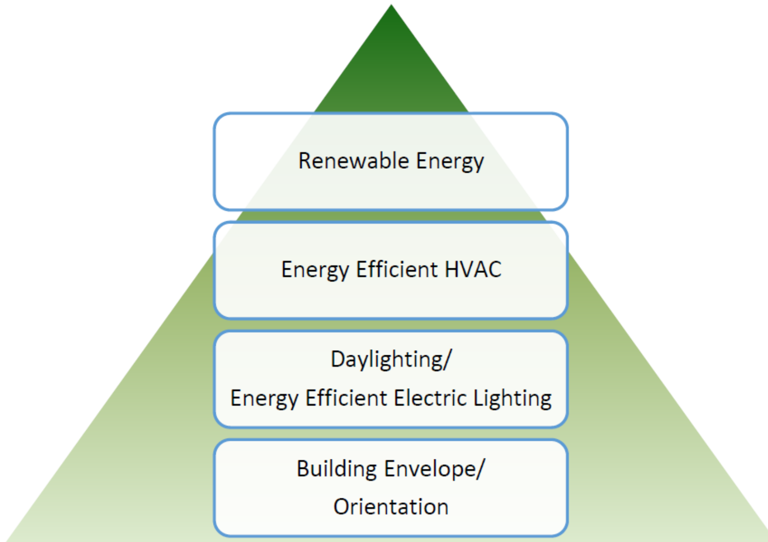


Figure 2. 4 Phases to Achieve NZEB [23]

This pyramid prioritizes the sequence of steps. The highest priority goes to reducing the demand of the building by employing energy conservation strategies such as day-lighting harvesting and inactive solar air-conditioning, followed by enhanced HVAC system and finally use of renewable sources. The study highlights the importance of reducing energy demand before electricity generation in the NZEB.

2.4.1 Overall Design Strategies to achieve NZEB

Torcelini [47] and Kolokotsa [27] outline the NZE Building design strategies in the order to develop NZEB framework. In the northern hemisphere, for example, a proper building orientation with good envelope design helps to avoid sunlight through the south facing side to minimize radiation heat gain, and well-designed landscaping on the east and west side of the building could keep the building cool during the hot seasons. Enhanced building envelope increases the building insulation and air infiltration. Proper thermal insulation reduces heat transfer thus, providing thermal comfort during summer and winter for the occupants. Airtightness stops the energy losses through infiltration where by standards, a high energy efficient building must have air changes per hour (ac/h) on the range of 0.35 and 0.5 ac/h without forced ventilation and ac/h of below 0.35 with machine-driven ventilation.

Effective lighting design and optimized HVAC system are respectively the second and third stages where the optimization of one system will lead to better results. For example, the use of low-U-value (U-value is the total heat transmission coefficient that defines how well a building component conducts heat or the rate of transfer of heat) windows with low solar factor and suitable coatings can maximize the natural sunlight and minimize solar heat gain. Also, the solar shields such as window overhangs can deliver shading to avoid solar gain or heat during the summer while more sunlight and heat throughout the winter by increasing the heating and cooling efficiency and lower load on HVAC systems. The last step the NZEB plan, is the generation of the electricity through existing renewable resources including photovoltaic technology (PV), solar water heating, geothermal heat pumps and wind turbines.

2.4.2 Renewable Energy Technologies

Utilization of renewable energy resources is technically achievable as an alternative to the existing fossil fuel-based electricity; but, economic issues represent the main challenge to generate power from a renewable technology on a large scale. The use of photovoltaic (PV) panels is one of the promising renewable technology which converts light into direct electricity [3].

PV technology is a sustainable, clean, renewable technology that is able to meet the energy growing demands of the globe, at the same time it will reduce the negative impacts of fossil fuel usage. Worldwide, the use of solar PV has increased from 0.26 GW to 16.1 GW from 2000 to 2011, with a progress rate of around 40% per year, because of technical innovations that have reduced processing costs by more than 100 times and several government motivations for producers and consumers as well [32]. If this rate continues, the PV power generation rate will replace yearly 5% of the present electricity generating size. However, keeping this progress requires reliability and lasting performance of PV panels, affordable costs and low enough risk to enable investment.

2.5 Energy Simulation Tool

The United States Department of Energy developed a list which contains around 415 energy modeling and simulation software for assessing energy performance in buildings[8]. This record shows that there is not one software which can fulfill the requirements of all clients. Some of the variances among these software's result from the main equations used in them, along with the related assumptions. This explains the differences in the results between the simulation software [51]. Although most of simulation software are different in a certain way, all of them have the same overall data framework as shown in Figure 2.5 [31].

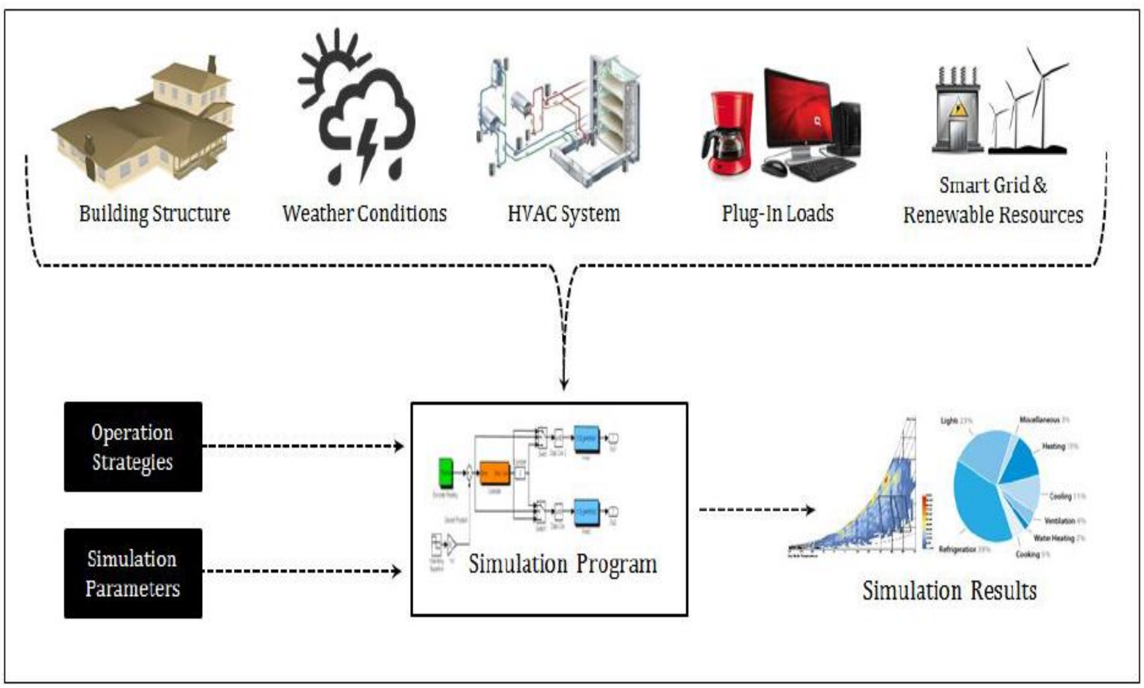


Figure 2. 5General Data flow framework of Simulation Engines.

2.5.1 eQUEST

DOE developed energy simulation software called (DOE 2) for buildings, and widely considered as the standard of market [32]. This software can perform comprehensive, hour by hour analysis of the entire building's energy on one or several units, affording important understandings of the performance of a building in terms of energy, and life cycle costing (LCC). eQUEST provides an analysis for demand side management (DSM), improvement and application of sustainability conditions (e.g. LEED, ASHRE). DOE 2 needs the building characteristics inputs, the building orientation and materials, operation practices, energy demand patterns, and weather and geographical data. Energy modeling and simulation taken from DOE 2 tool is suitable for evaluating different building proposals and operational plans. DOE 2 has a disadvantage regarding the need for deep and extensive training to master the tool.

DOE 2 engine is a source for many commercial applications in the market. These applications provide users more facilitated interface to logically and easily enter the inputs. eQUEST is an interface application using DOE 2 engine for processing data. eQUEST is capable of providing detailed analysis of current best technologies in building design and the latest, most complex methods for building energy modeling and simulation with minimum experience in building performance modeling. This is achieved by mixing a 3D building model creation wizard, a wizard for energy efficiency measures (EEMs), and graphical simulation report.

2.5.2 TRNSYS

Established in the late 70s, TRNSYS stands for Transient Systems Simulation [26] is a robust and comprehensive energy simulation software used for performance analysis of different systems. TRNSYS is very flexible and a customizable tool. It has a large built-in collection of objects which builds things from a simple lighting system to large buildings. A key advantage of this tool is the end-user friendly interface. It uses drag and drop simple tasks to design very complicated systems in the engineering field. The models are developed in TRNSYS by joining separate parts in one map, enabling for a variety of energy systems to be modeled without any limitations. TRNSYS is interactive and dynamic to inputs changing, so the result of the change in any input value will be reflected on the related system variables immediately. One disadvantage of the tool is that it provides no assumptions about the building common inputs for different systems. Thus, it is essential to get detailed information for every component of the building model before starting TRNSYS. [45].

2.5.3 EnergyPlus

EnergyPlus is a DOE-2 based energy simulation tool with combination of the BLAST (Building Loads Analysis and System Thermodynamics) program[6]. EnergyPlus is considered one of the strongest building energy simulation softwares in the market. It was established in 1996 by the DOE in the United State, and it enables for the analysis of incorporated strategies in energy performance. EnergyPlus uses comparative “Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs

BESTEST/ASHARE STD" to validate the models [22]. It utilizes the top abilities of BLAST tool and DOE 2 engine, in addition to new features to enable flexibility in its programs and third-party application compatibility. EnergyPlus mainly estimates the amount of heat and cool needed for the building. As inputs, EnergyPlus uses mechanical system requirements and the building's characteristics, the required inputs to provide thermal comfort, the energy demand of different components, and some other essential inputs. In addition to energy performance analysis, EnergyPlus can be used to model natural ventilation, photovoltaic (PV) technologies, water usage, green roof, thermal comfort and different energy saving measures.

2.5.4 AutoCAD 2017

The existing building prototype drawings were drafted in AutoCAD which is a 2D and 3D design and drafting software developed by Autodesk.

2.5.5 PV Watts

PV Watts online software was used to determine the monthly energy generated from the photovoltaic system. PV Watts estimates the electricity production and cost of energy of grid connected photovoltaic energy system for numerous locations worldwide.

2.5.6 DOE-2 Building energy Simulation

(DOE) developed energy simulation software called (DOE_2) for buildings, and widely considered as the standard of market[32]. This software can perform comprehensive, hour by hour analysis of entire building energy on one or several units, affording important understandings of; the performance of a building in term of energy, and life cycle coasting(LCC). DOE 2 needs a building characteristics inputs, the building orientation and materials, operation practices, energy demand patterns, and weather and geographical data. Energy modeling and Simulating taken from DOE2 tool is suitable for evaluating different building proposals and operational plans. DOE 2 has a disadvantage regarding the need for deep and extensive training to master the tool. DOE 2 engine is a source for many commercial applications in the market. These applications provide users more facilitated interface to logically and easily inter the inputs.

CHAPTER 3

DEVELOPMENT OF THE SCHOOL MODEL

3.1 Introduction

To establish reasonable design criteria for Net-Zero energy school in mild climatic condition in Saudi Arabia(SA), a prototypical governmental school model was selected to evaluate its energy performance (EP) against industry standards and regulations, in order to (1) find out the most critical design factors affecting the energy performance, (2) identify the most suitable Energy Conservation Strategies and renewable energy alternatives, (3) Maximize the cost-effectiveness of the proposed criteria.

(1) Selection of The Case Study

The selection of a typical public-school building in the case study represents the public schools' standards and specifications at mild climatic areas. Climatic data will be collected for the location.

(2) Development of a Baseline Model

With help of Building Information Modeling (BIM) tool and Energy Simulation software, the (EUI) of the Calibrated model will be found and benchmarked against industry's models. The model will be validated by comparison with actual data.

(3) Estimate the Available Solar Energy amount

Estimate the solar radiation on the site and find the available roofs area for Photovoltaics(PVs) panels.

(4) Development of the NZEB Building Model

The proposed building model is established by modifying an integrated set of energy efficiency measures (EEMs) to the baseline building model and harnessing the onsite solar energy.

(5) Study the Cost Effectiveness of the Proposed Strategies

Lifecycle costing for the employed passive and active measures

3.2 Climatic and weather analysis of mild Areas in SA

Mild areas in SA are mainly mountainous districts in south-western. These cover around 100,000 km^2 and consist of mountains, steppes, and valleys. The climate is classified as mountainous subtype zone thus, the temperature decreases as altitude increases. This area tends to have much wetter climates than the surrounding flat land. Generally, the mean temperature for the year is 18.3°C. June has the highest month average temperature with 23.3°C, and in contrast, the coolest month is January, with a mean temperature of 13.3°C. (the Presidency of Meteorology and Environment in Riyadh, KSA,). For this reason, Abha city is selected to represent the target climate zone. For the baseline model simulation, decent climate data source of Abha City is a critical factor for building energy performance analysis. The Climate Server by Autodesk affords access to a database of weather and climate data on an hourly basis. The data come from physical weather stations such as airports [30]. The weather file is used in the baseline model, which can provide insights about passive design strategies such as natural ventilation and solar utilizations. Weather Station: 180070 (Abha Airport) at 3.2 km from school, which is the closest station to the reference building to conduct the analysis more precisely.

3.3 Case Study

The study will evaluate the existing prototypical Ministry of Education (Department of Projects) public school building. All standards and specification of the Ministry will be applied in order to establish the as-built baseline. The case study is the Eighteenth Secondary School of Girls in Abha City, with latitude of 18.2° and longitude of 42.6°. The school is a three-story building with classrooms, laboratory and office spaces. The design process was conducted by an in-house team. The school opened in December 2010. The school is connected to the local utility grid as the only source of power. All necessary data have been collected including design plans and documents, unified standards and specifications of public school buildings, users, utility bills, equipment, and operating schedules.

3.4 Building Form and Orientation

The school building is a 3509 m² three-story building. The existing building has a square shape with dimensions of 42.4 mby 35.2 m with 240 m² inner atrium Figure 3.1. The square shape results in a neutral orientation of the building. Forms and orientations for public schools differ greatly depending on the site characteristics. Most of the school building designs can be described as square shaped. The orientation of buildings is elongated along the ESE-WNW axis.

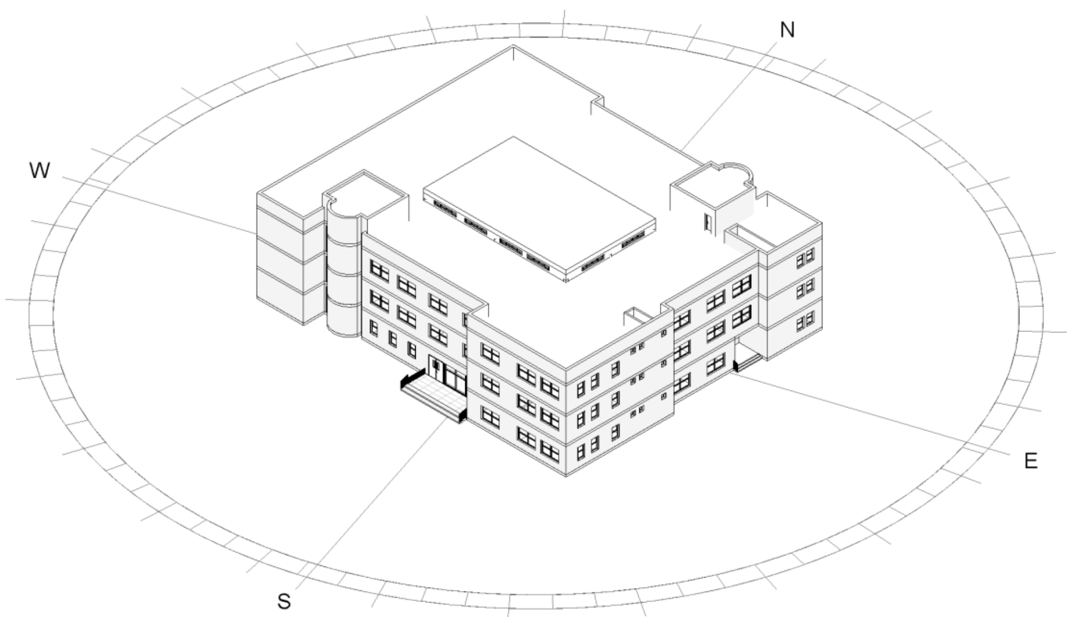


Figure 3. 1 3D View and the orientation of school building

3.5 Building Operating Characteristics

Operating hours of the Eighteenth Secondary School of Girls are collected as actual for the targeted study period with peak occupancy occurring from 6 AM to 3 PM weekdays with partial occupancy starting from 4 AM until midnight to include cleaning and maintenance works. For Friday and Saturday occupancy is between 10% and 30% of the peak and limited for vacation with approximately 5% occupancy. Schedules for electric lighting and various equipment are coordinated to occupancy schedules with additional limited usage during unoccupied times. AC system schedule starts earlier to cool the space till the desired temperature before major occupancy. The occupancy, AC, lighting, and plug load schedules are taken according to the actual operation of school. Figure 3.2 shows the weekday occupancy and operating schedules.

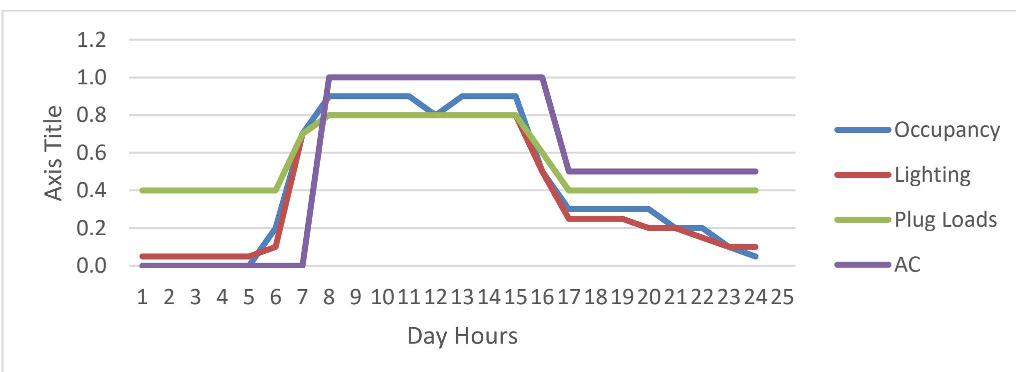


Figure 3. 2 Weekday Occupancy and Operating Schedules

However, these schedules are used as uniform inputs to all spaces in the building model. The analysis assumes that the school building typically has different space usages. These space types are modeled individually to represent a more accurate model.

3.6 Building Envelope Characteristics

The structure of the building is mainly reinforced concrete including insulated external walls with plaster on both surfaces, insulated flat roof and non-insulated slab on grade floor. Windows are framed by aluminum and have single tempered pane glass with no shading devices. The baseline model represents the envelope characteristics of the existing building and according to Ministery of Education specifications and Standards. The layout of the spaces is illustrated in Figure 3.3 to Figure 3.5**,** they include zones, activity and occupation.

3.6.1 Exterior Walls

The exterior walls of the Eighteenth Secondary School are hollow walls with an overall thickness of 300mm with core structure of two faces of cement block having dimensions of 15 cm by 10 cm and hollow cores with interior thermal insulation in between. The exterior walls include the following layers:

- Exterior cement plaster coated with paint, U-Value is 0.72 W/ m. K
- 100-mm concrete block, U-Value 1.3 W/ m. K
- 40-mm Rigid polystyrene insulation fixed with metal clips, U-Value 0.04 W/m. K
- 150-mm concrete block, U-Value 1.3 W/ m. K
- Interior cement plaster coated with paint, U-Value 0.72 W/ m. K

The overall thermal properties of external wall for the baseline model are:

R-value 1.62 ($m^2 \cdot K$)/W, and thermal mass is 35 kJ/K. R-value is the ability of an element to resists heat transfer.

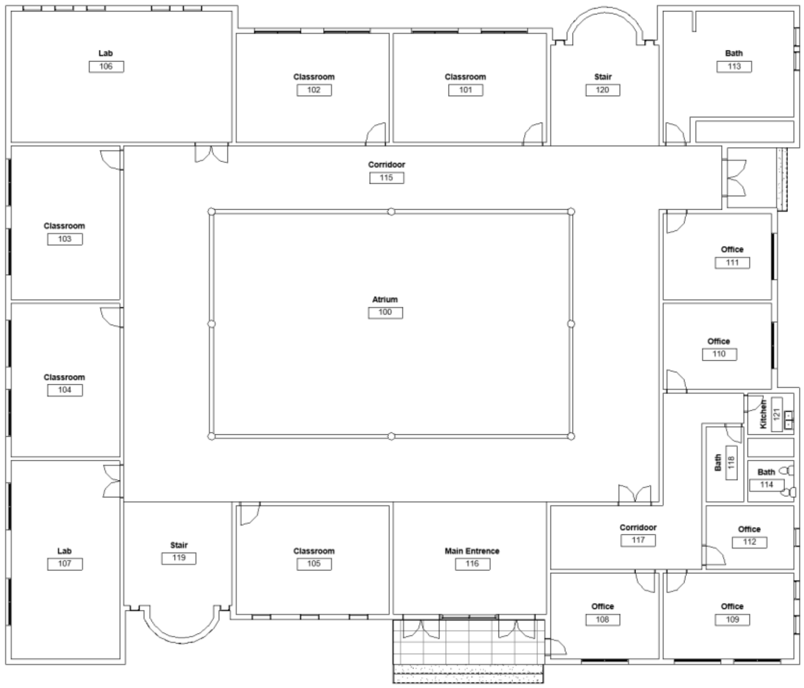


Figure 3. 3 First-Floor Plan

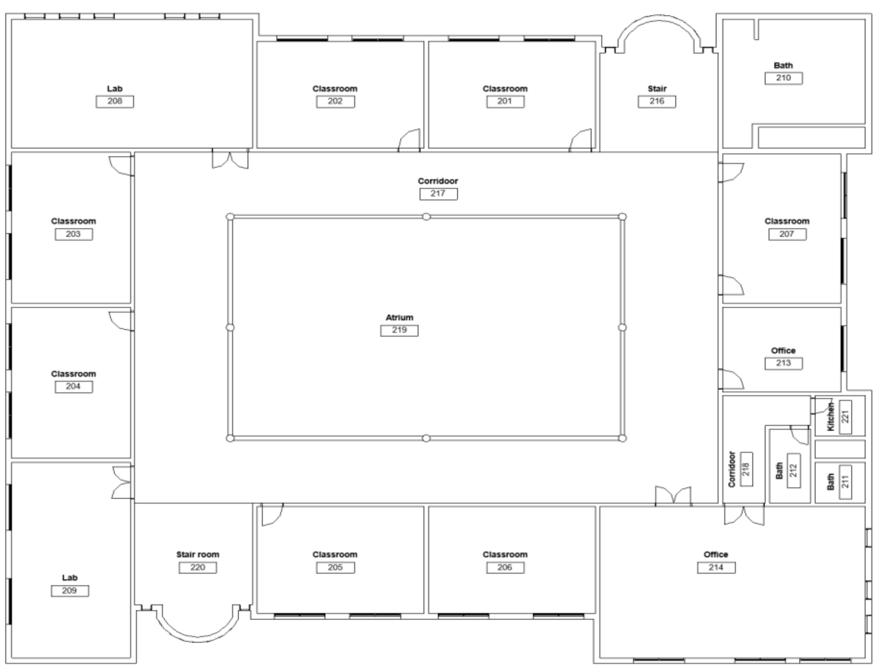


Figure 3. 4 Second-floor plan

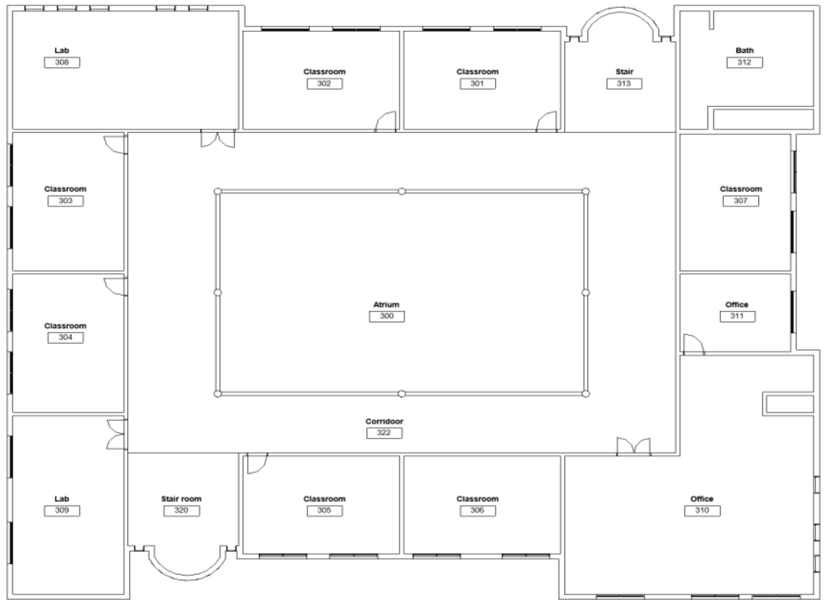


Figure 3. 5 First-floor plan

3.6.2 Roof Construction

The school building roof is flat and it consists of a roof waterproofing layer as the outermost layer, thermal polystyrene, bitumen felt/sheet, cement screed, over concrete. The total thickness is 280 mm, with an overall R-Value of 1.37 $(m^2{\cdot}K)/W$.

The atrium roof consists of thermally insulated hollow panel over steel bar joist with an overall R-Value of 1.43 $(m^2{\cdot}K)/W$.

3.6.3 Floors Characteristics

The floor of the school building is ceramic tile having a thickness of 70mm over sand/ cement screed and the ground floor is poured over cast-in-situ concrete casted directly on to the ground (slab-on-grade). The overall thermal resistance is 0.3448 K·m2/W and the soil conductivity is 1.3 W/m²·K.

3.6.4 Building Apertures

The window used in the school is slider fix type where the lower half is fixed and the upper half is sliding. All windows are aluminum framed and single glass pane with rubber window seals. The windows have the following specifications:

- Visual light transmittance, 0.9 out of 1
- Solar Heat Gain Coefficient, 0.86
- Thermal resistance (R), 0.1743 (m²·K)/W
- Heat Transfer Coefficient, 5.74 W/(m²·K)

All external and internal doors of the school are fire rated hollow metallic doors, with thermally insulated core by polyurethane thermal resistance (R), 0.49 (m²·K)/W.

Figure 3.6.

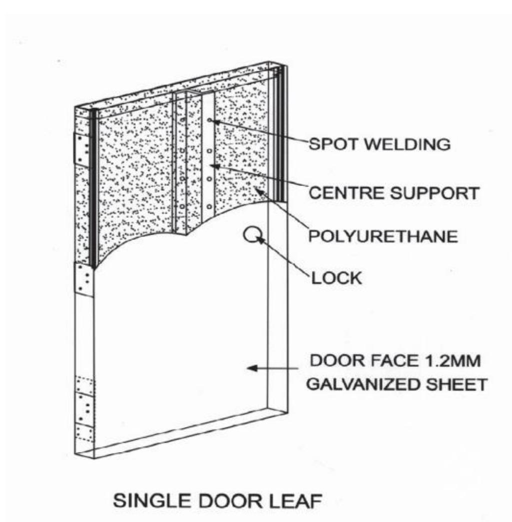


Figure 3. 6 Door Details

The school building has moderate window-to-wall ratios (WWR). Figures 3.7 to Figure 3.10 show the windows distributed around the building facade. All upper half of the windows in the classrooms, labs and offices can be opened manually. The atrium has clerestory window with same glass type of wall windows but with only sliding pane which allows daylight and natural ventilation during moderate seasons.

Figure 3. 7 South View

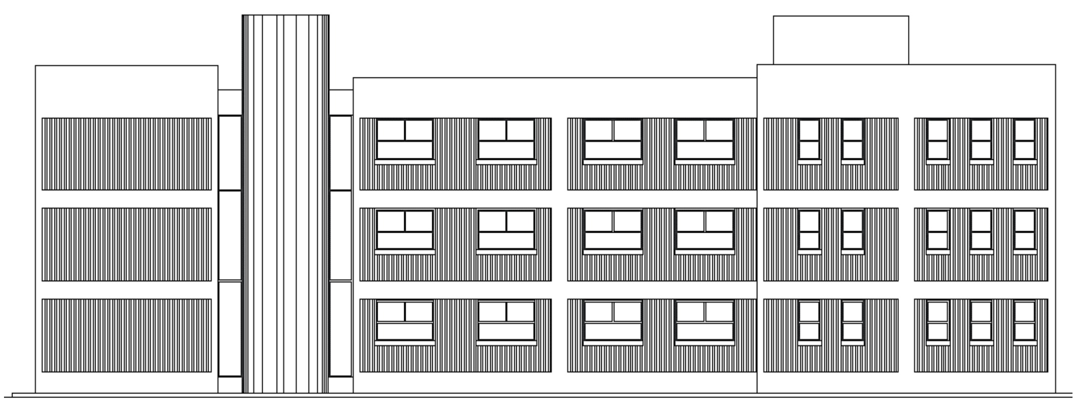


Figure 3. 8 North View


Figure 3. 9 East View


Figure 3. 10 West View

Table 3.1 summarizes the window-to-wall ratio for the four facades of the building. The high window-to-wall ratio of the south façade is due to the glass curtain wall in the entrance. The overall fenestration ratio is 17% of the total wall area. **Table 3. 2** Summarizes all thermal properties of the reference building envelope elements.

Table 3. 1 Window-to-wall ratio for the four facades

	South	North	East	West
window-to-wall ratio(WWR)	20%	17%	14%	17%

Table 3. 2 Summary of Thermal Properties of Building Envelope Elements

Envelope Element	Element Construction	Overall R ($m^2 \cdot K/W$)
External Walls	Exterior cement plaster coated with paint, 100-mm concrete block, 40-mm rigid polystyrene insulation, 150-mm concrete block, interior cement plaster coated with paint	1.62
Internal Walls including Atrium walls	Exterior cement plaster coated with paint, 200-mm concrete block, interior cement plaster coated with paint	0.15
Windows	Slider Fix type where the lower half is fixed and the upper half is sliding, aluminum framed and single glass pane with Rubber window seals	0.17
Doors	Fire rated hollow metallic doors, with thermally insulated core by polyurethane	0.49
Atrium Roof	Waterproofing layer as the outermost layer, thermal polystyrene, bitumen felt/sheet, cement screed, over concrete; The total thickness is 280 mm.	1.37
Building Roof	Thermally insulated hollow panel over steel bar joist	1.43
Floors	Ceramic tile 70mm over sand/ cement screed over cast-in-situ concrete	0.35

3.7 Internal and External Loads

3.7.1 People

The number of the peak occupancy for the school is set at 760 users. This comes from the prototypical design and from data collected for the school. An area of 1.5 m^2 is specified for one person on school classroom and laboratory and 9 m^2 is specified for enclosed and open plane office. The occupancy of the circulations areas are calibrated to represent the existing school situation. Some inactive spaces are set at 20 m^2 per person occupancy and has minimal contribution to the total occupancy. For the calibrated model, the following parameters are used:

- People Activity Level, Standing, Light Work, Walking
- People Sensible Heat Gain, 73 (W/person)
- People Latent Heat Gain 59 (W/person)

3.7.2 Electric Lighting

The indoor lighting spaces include restrooms, kitchen, circulations, classrooms, offices, atrium, and laboratories. **Figure 3.11 to Figure 3.13** illustrate the types and locations of each lighting fixture.

3F= Fluorescent Lights Unit (3x 40 Watt)

2FC= Fluorescent Lights Unit (2 X 40 Watt)

 = Incandescent Lights Unit (60watt)

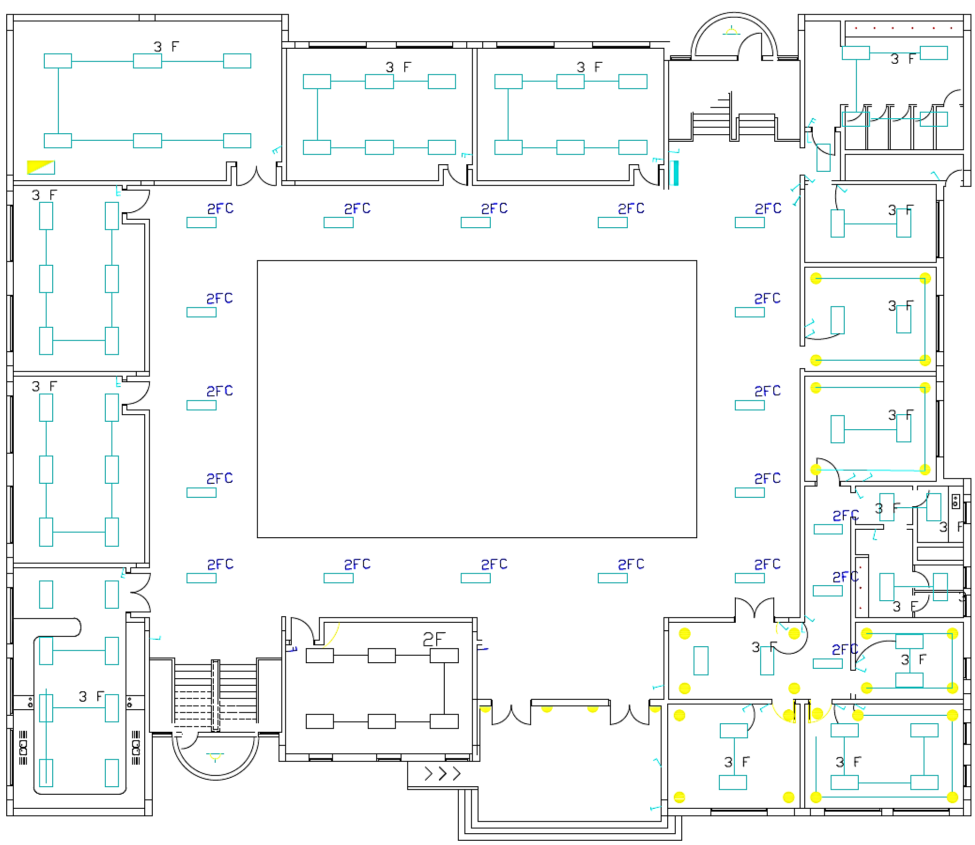


Figure 3. 11 Electric lighting System Level-1

All lighting fixtures are manually controlled, and each space has many lamp switches. All interior rooms have fluorescent lamps. The atrium has 19 incandescent halogen lamps. Atrium has limited sun light from the clerestory, as defined by the original plans of the building.

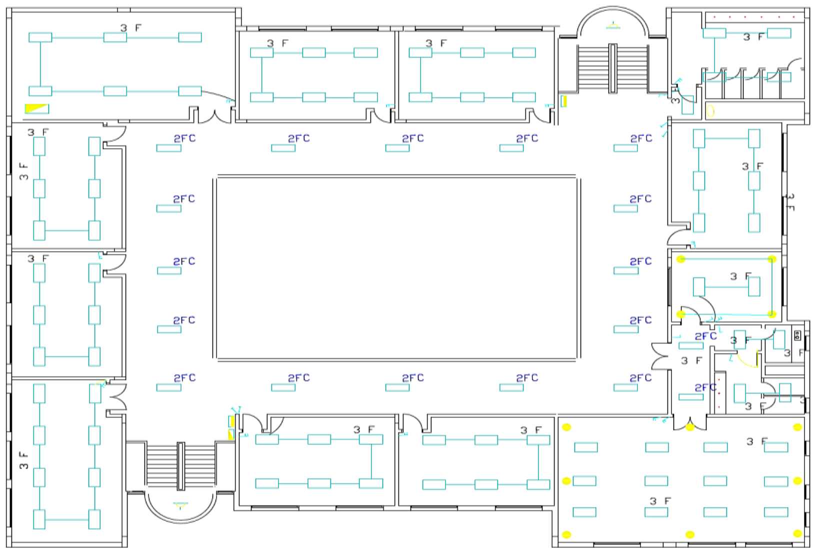


Figure 3. 12 Electric lighting System Level-2

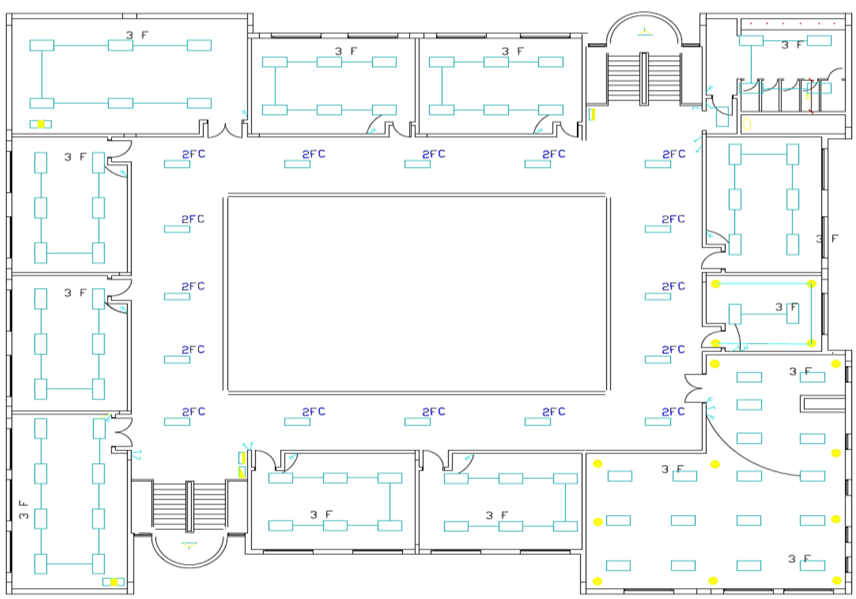


Figure 3. 13 Electric lighting System Level-2

The electrical lighting systems has no lighting control techniques such as timers, dimmers, and no automatic occupancy sensors to turn lights on or off accordingly. The classrooms, offices, restrooms, have more lighting intensity (W/ m^2) than the corridors and stairways. Table 3-3 shows Lighting Load Density(LLD) by space type. The indoor area lightings do not include any accent, task lighting.

Table 3. 3 Lighting Load Density(LLD) by space type.

Space Type	Area m^2	Percentage of total Floors Area	Lighting Load Density (W/m^2)
Atrium	218	6	6.46
Classroom	907	26	15.07
Corridor	949	27	5.38
Hall	76	2	5.38
Kitchen	13	0	12.92
Lab	577	16	15.07
Main Entry	49	1	5.38
Office	262	7	11.84
Restroom	153	4	9.69
Stairway	308	9	6.46

Each space in the calibrated model will have the matching LLD value according to the space type as shown in the table above.

3.7.4 Plug Loads

Plug loads include any product that works by using the electrical outlets in the building excluding HVAC or artificial lighting. In heavily occupied buildings, plug loads have a significant impact on room loads, while plug load schedule is playing an important role in assessing building energy usage intensity. Table 3.4 summarizes plug loads in the school.

Table 3. 4 Plug Loads in The School

	As-Built Model		
Equipment	Qty	Rated Power Item (watts)	Plug Load (W)
Desktop computer	44	65	2860.00
Notebook computer	44	19	836.00
LCD Display	88	35	3080.00
laser printer	3	215	645.00
Copy Machine	1	1100	1100.00
Refrigerator	3	76	228.00
Electric Stove (Cooking Range)	1	2200	2200.00
Microwave	1	1100	1100.00
Vacuum Cleaner	1	1500	1500.00
Coffee Machine	1	1100	1100.00
Tee Water Boiler	3	1500	4500.00
fax machine	1	170	170.00
overhead and digital projectors.	17	260	4420.00
Drinking water cooler	6	120	720.00
Total Equipment Loads			**24459.00**
Plug Loads Density W/m2			**7.59**

3.7.5 HVAC Systems

The Ministry of Education in Saudi Arabia has set the standards and specifications for room air conditioning and are mentioned here in detail. For conditioned spaces, in summer the dry-bulb temperate must be 24°C (± 2°C) and the wet-bulb temperature is 50 °C (± 5°C), and in winter the dry-bulb temperate must be 21°C (± 2°C) and the wet-bulb temperature is 7 °C (± 5°C), The ventilation system is designed to have air change per hour of 2-6 times per hour(16.99-25.49 m3 /hour). For the case-study, heat pump mini split air conditioning units are used as the type of cooling/heating system in the rooms. The ventilation supply air for the atrium, offices, classrooms, and corridors is considered to be naturally ventilated. For laboratories, kitchens, restrooms, exhaust fans are used to supply the air into the spaces. Exhaust fans have the value speed of 4.57 m/s. All design parameters of air conditioning or ventilations unified for all school types. Table 3.5 summaries the HVAC systems in the school building.

Table 3. 5 HVAC System in The School Building

Space type	**A/C Type**
Offices, Classrooms Laboratories	24000 BTU/h, heat pump Mini Split Units, direct expansion air conditioner working with R407C as an R22
Corridors	36000 BTU/h, heat pump Mini Split Units, direct expansion air conditioner working with R407C as an R22
Atrium	Open to the corridors
Restrooms	NO A/C
Stairways	No A/C

CHAPTER 4

Whole Building Performance Simulation

Technological developments have enabled designers the ability to test their designs performance and get immediate insights regarding their design. Within the situation of (NZEB), incorporating energy performance simulation in design process is critical step for project design optimization, in shaping the possible energy savings in buildings, and Prioritize energy efficiency measures. Energy performance of a building is subject to interdependent factors; thus, whole building energy analysis is the only approach to achieve the highest outcomes for new and existing buildings. It includes the follow the steps:

- Data collection of existing situations –geometry of the building, utility bills, materials and equipment characteristics, weather data, operating schedules, equipment Schedule and Loads.
- Creating whole building energy model– Using available data.
- Validation the model to ensure simulation results go with utility history within acceptable threshold
- Energy efficiency measures – Apply Modifications to energy model to create model of required energy performance target.
- Estimate costs for proposed measures and prioritize list based on costs-effectiveness methods.

4.1 Simulation Model Types

Investigation for zero energy building schools must comprises Baseline and Calibrated models to provide valued tool through the design and operational stages. Baseline model basically used for assessment purposes as benchmark for testing as-built model or design model. The calibrated model (as-built) must represent the existing situations, including weather, building characteristics and operating conditions.

calibrated model will be created to reflect the most accurate collected data of existing conditions of the school building. Moreover, School model based on ASHRAE 90.1, and The Architecture 2030 are modeled to serve as benchmarks to the reference model. The ASHRAE 90.1 benchmark sets minimum efficiency requirements for HVAC systems, elements thermal properties, and lighting density for schools. The Architecture 2030 benchmark is targeting 70% more than the Median of comparable school buildings. The calibrated model will be verified by comparing actual data with simulated one and reduced gap if any deviations exist. Whole Building Performance Simulation provide valuable indicators include potential energy savings and associated operating energy savings.

4.2 Energy Simulation Tools

Green Building Studio (GBS) is a cloud-based simulation engine powered by a DOE-2.2 and has been tested against ANSI/ASHRAE 140. GBS is using EnergyPlus tool to calculate heating and cooling loads and also have been tested and verified against ANSI/ASHRAE 140 Figure 4.1. GBS solar analysis uses an optimized Perez sky model and overshadowing calculation, validated with NREL provided test values. [4] [12] [33]

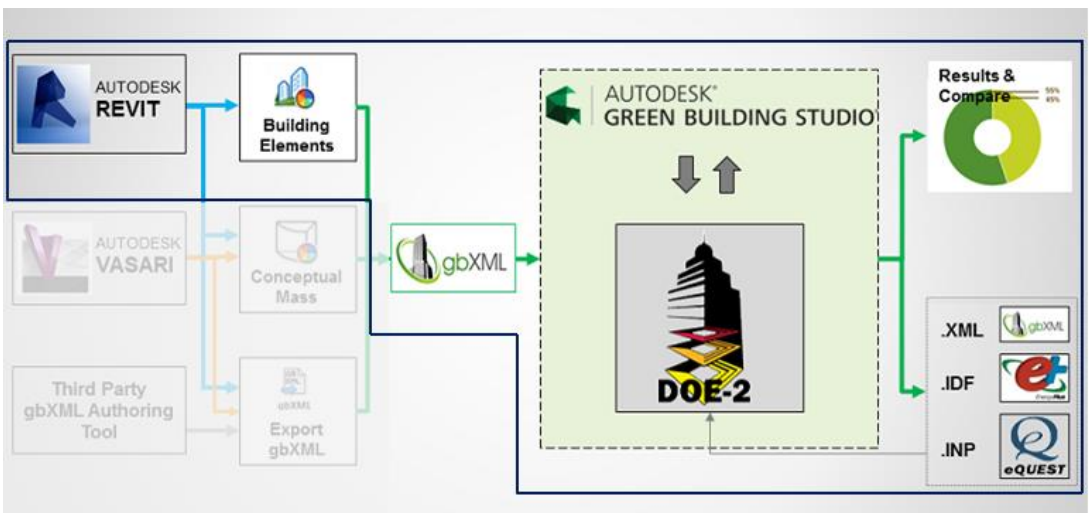


Figure 4. 1 Green Building Studio integrates with DOE-2.2 and EnergyPlus

4.3 Development of Calibrated As-built Models

After all the required data of the school has been collected and analyzed previously though out this chapter, the building As-built model is developed using Autodesk Revit Figure 4.2, and based on the that, a Building Information Modeling(BIM) tool is created. This model includes; geometry of the school the characteristics and thermal properties of the envelop, HVAC parameters, occupancy, plug loads, and light loads.

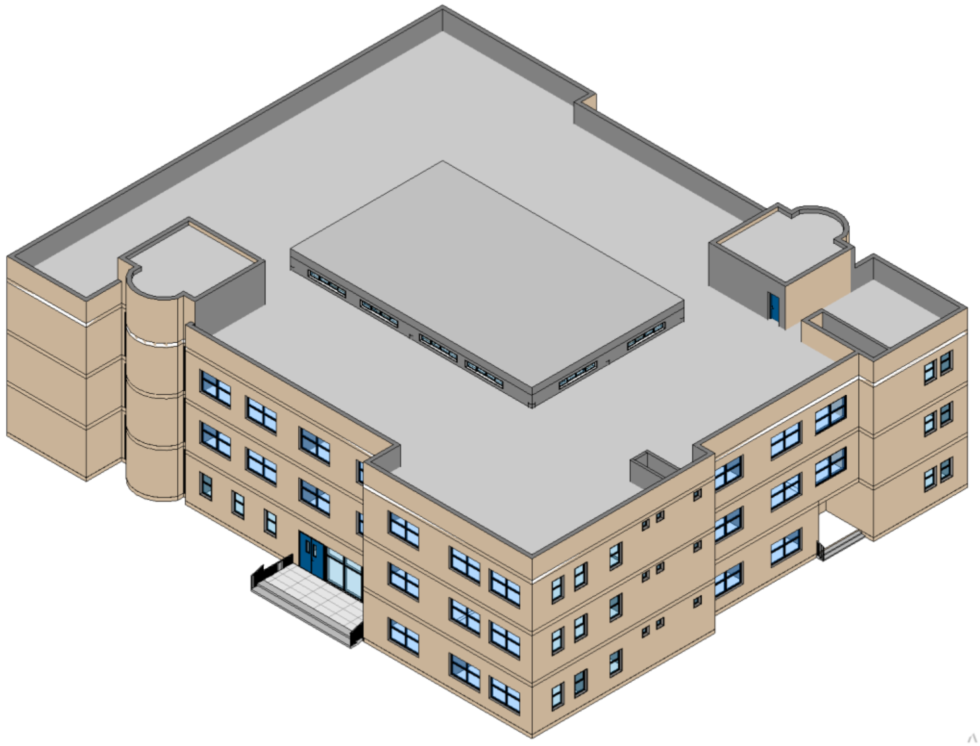


Figure 4.2: As-built model(BIM) of the school

The Energy Analysis Model (EAM) is devided into zones that are in compliance with industry conventions (ASHRAE) Standard 90 Figure 4.3. Each room is considered as a separate space includes; the using types, the activities, and different loads within these spaces, this approach helps to create more accurate model.

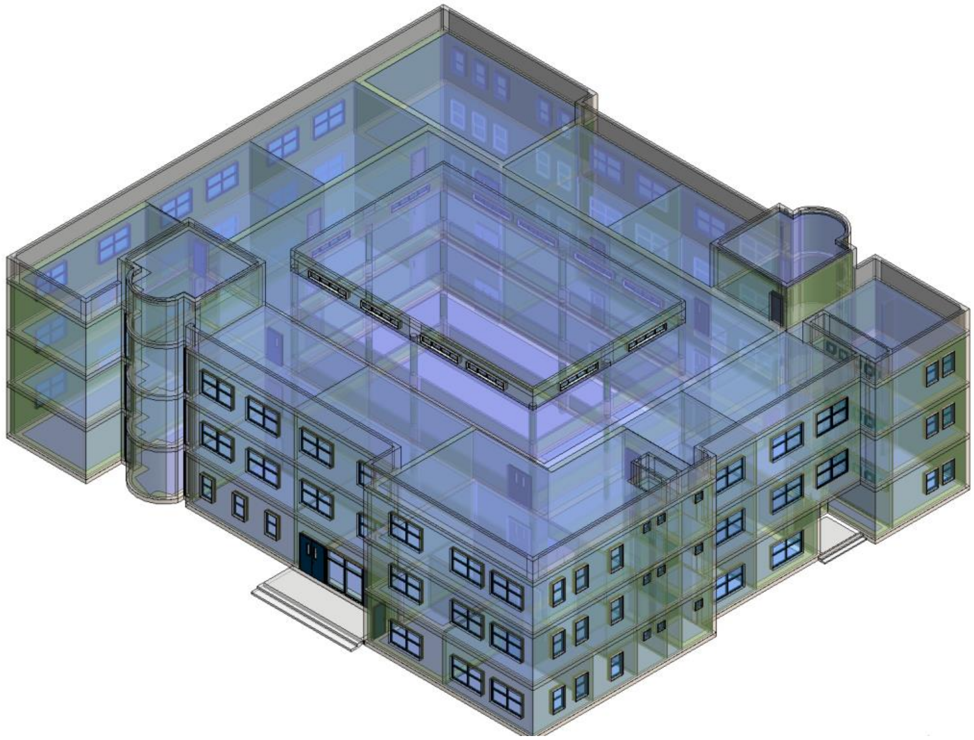


Figure 4. 3 The Energy Analysis Model (EAM) Zones

Figure 4.4 shows how the actual data was used to perform energy analysis using Revit and Indight360 tools to get the simulation results.

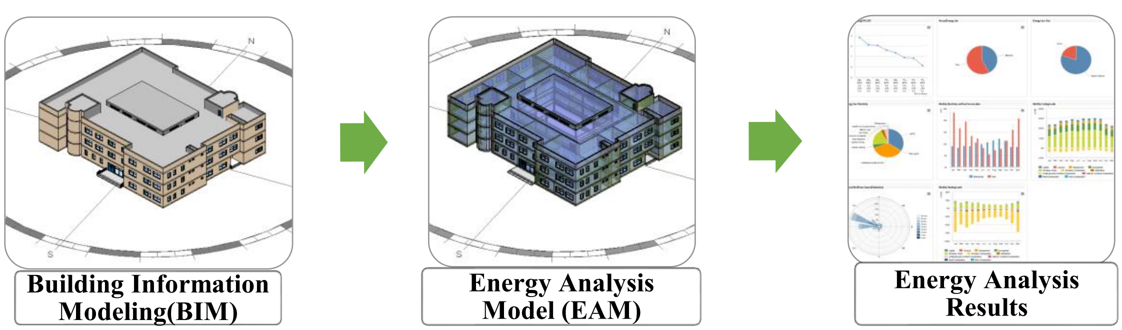


Figure 4. 4 Process to perform energy analysis for the school.

4.4 Characteristics and Energy Profiles of The Reference Building

A calibrated as-built model and a reference ASHRAE Standard 90.1 model were simulated for the targeted weather and the same operating schedules. As-built models were calibrated against actual performance by driven by operating schedules.

The purpose of energy simulation is to identify the annual energy consumptions breakdown and the energy use intensity(EUI) of the school to set a starting reference to quantify the possible potential factors for energy savings. The results of the energy simulations exposed high energy use in the areas related directly to the occupant's behaver such as lighting and plug loads. The energy use intensity(EUI) of the *As-built model*, scores are 134 kWh/m2 which is better than ASHRAE 90.1model performance with an EUI of 136 kWh/m2. And higher than Arch2030 Zero Energy benchmark (67 kWh/m2) Table 4.1. The Arch benchmark is the study goal to reach zero energy school building. The total annual energy demand and the corresponding energy cost are illustrated in Figure 5.30

Table 4. 1 EUIs of as-built model, ASHRAE 90.1 and Arch 2030

Model Name	**Cost Mean** ($/ m²/yr)	**EUI Mean** (kWh/ m²/yr)	**Arch 2030** (kWh/ m²/yr)	**Ashrae 90.1** (kWh/ m²/yr)	**Building Area**
Abha NZEB School	9.67	134.4	67.1	136.2	3223(m²)

Energy simulations outcomes provided an understanding of the annual energy consumption by end use of this reference school. From the total annual energy uses, the area lights consume 38% of energy scoring the highest one. Plug loads are all appliances and devices in the school except the HVAC system and lighting and they use 29% energy. Spaces cooling uses 18% Energy consumption in Fans, Pumps & Aux. is 13% and that includes heat exchange with the air. of the total energy. Finally, 0.5% of annual energy is used in space heating, pumps and others Figure 4.5.

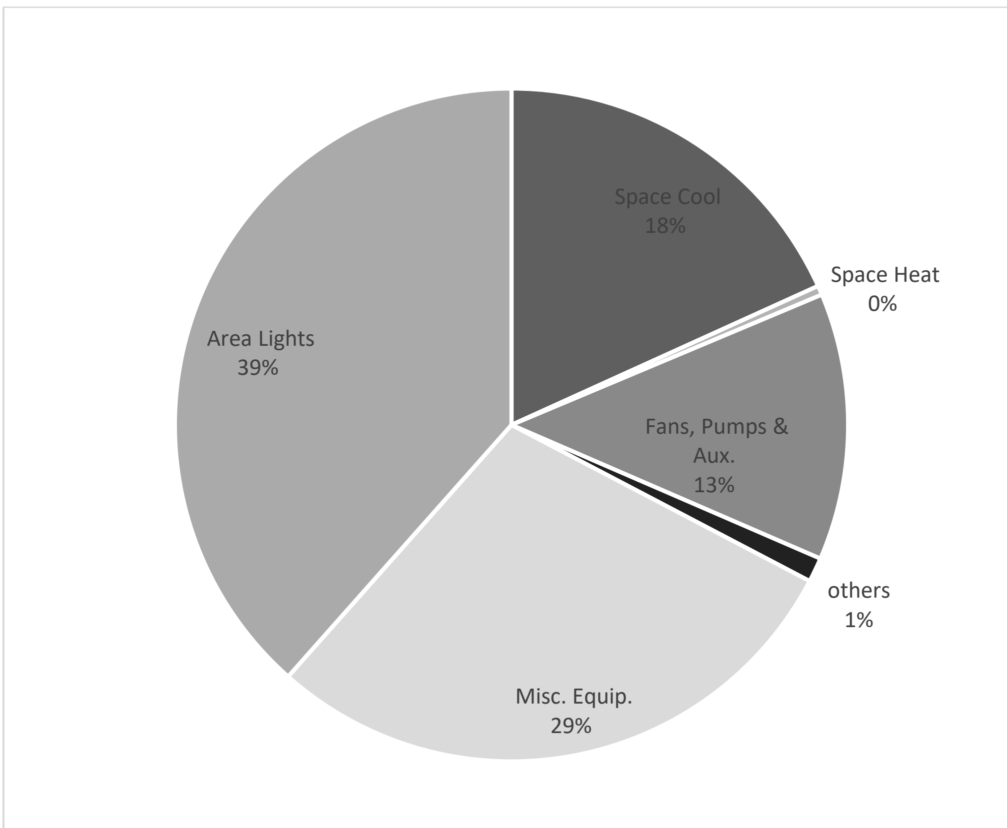


Figure 4. 5 Annual Energy Consumption by End use

4.5 Simulation Validation

Comparing the energy performance of the model to the actual energy performance of the building is crucial for NZEB projects. In this research the energy simulation is carried out using Autodesk GBS. This tool is working DOE2.2 to calculate the energy consumption of the building and it also interacts with EnergyPlus to calculate heating and cooling balance of the spaces. DOE-2 and EnergyPlus are heavily tested and validated tools. (http://apps1.eere.energy.gov/buildings/EnergyPlus/testing.cfm). Comparing simulated energy results with actual energy consumption data, is an important tool to find gaps between the building design and operation, inefficiencies of the systems and to give insights about energy efficiency measures that could improve building energy performance. In this thesis, the actual school plans and specifications for construction have been included in the model. The spaces in the model to reflect the most accurate set of existing conditions such as, existing devises and equipment, performance information (such as enclosure leakage), and include actual environment and occupancy types in each room as described earlier in chapter 3. The simulation outputs display a large list of hourly, monthly, and annual results and summary report. Another additional model based on ASHRAE 90.1 was developed to compare its energy performance with the as-built model for the sake of more reliable results. The ASHRAE 90.1 model is subjected to the same climatic conditions and geometry but has the specifications of ASHRAE 90.1 for school types. The EUI results of as-built is model 134.4 (kWh/ m^2/yr.) which is close to EUI of Ashrae90.1 that equals to 136.2 (kWh/ m^2/yr.). Coefficient of variation of the root mean square error CV(RMSE) and Mean bias error (MBE) and the is A widely used method to evaluate the simulation predicted results by comparing the simulated value to the actual one[2]. CV(RMSE) is a measurement of how uncertain the prediction is and calculated according to equations 4.1 and 4.2, and the simulated values are acceptable if CV (RMSE $_{month}$) (%) ≤ + 15%. [46,47. The RMSE of a model predicted value with respect to the actual variable defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (M_{month} - S_{month})^2}{n}} \tag{4.1}$$

$$CV(RMSE_{month})\% = \frac{RMSE}{A_{month}} \tag{4.2}$$

Where:

M_{month} is actual values and

S_{month} is simulated values at month i

n is the number of months and,

A_{month} is the average monthly actual variable.

Table 4. 2Validation of the energy model: CV(RMSE)

Month	Actual Consumption(M)	Simulated Consumption(S)	$(M-S)^2$
January	36856	35993	745032
February	38972	36321	7026103
March	43385	41706	2819894
April	37416	36254	1350280
May	49976	48438	2364171
June	29959	27588	5621567
July	22657	20254	5775498
August	28865	27300	2448430
September	45844	43972	3503448
October	47415	45020	5733873
November	40683	38999	2834567
December	33050	29178	14990872
$RMSE_{Month}$ = 2145.03			
CV ($RMSE_{Month}$) = **6%**			

Table 4.2 and figure 4.7 reveal that the energy model satisfies the acceptable values of CV ($RMSE_{Month}$) calibration which is less than is 15%. Moreover, the simulated model can be used to apply different modification measures and to calculate energy performances for proposed alternatives.

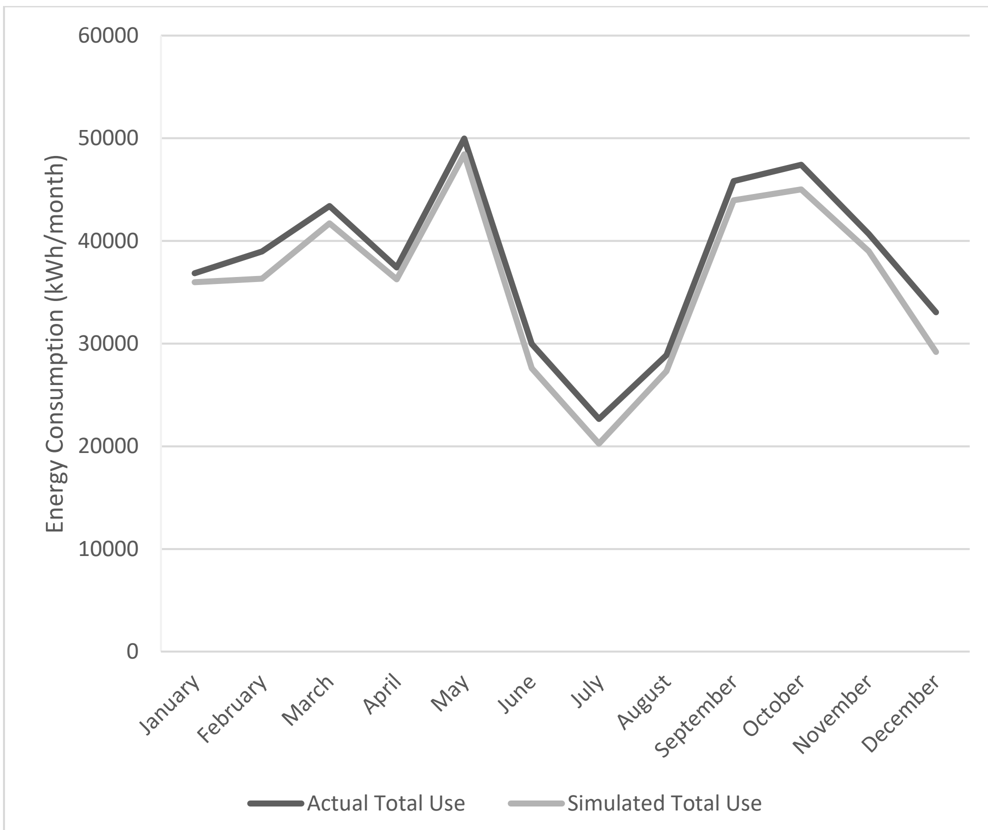


Figure 4. 6: Energy use comparisons between actual data and simulated results

4.6 School Factors Sensitivity Analysis

In order to find the building factors that have the most impact on energy performance, the first step is conducting sensitivity analysis for different factors and see the effect on total school energy use. This is an important step before any energy conservation measures (ECMs) will be proposed. Therefore, a large number of energy simulations on different scenarios have been carried out in order to evaluate the sensitivity of the building factors on the energy performance. After that, the most influencing factors are selected to be evaluated technically and economically in order to optimize the proposed energy conservation measures (ECMs). This method will yield an advanced model with better reliability and accuracy.

A set of 21 separate building factors that influence the total energy consumption was identified, representing operational and physical features of school. For each Factor, a range of associate performance input values was simulated representing worst, as-built(BIM) and best outcomes in terms of building energy performance. These values were taken from best practices and industry standards such as ASHRAE90.1[1] [9] [49]. The relationship between the energy use intensity (EUI) and each variable is recorded individually, as the inputs were changed from worst to best, while all other features of as-built(BIM) were fixed. For example, to examine the impact of window-to-wall ratio on school energy use, the model was run with a minimum value for the (0%) and a maximum value (90%) while keeping the remaining inputs of the baseline fixed. Moreover, different packages of measures were also examined for further investigations. With 21 factors, different input ranges were simulated. The simulation results obtained by performing (246) base runs. the whole simulated scenarios results of this analysis can be found in Appendix C. Table 4.3 shows alternatives input ranges for all factors.

Table 4. 3: Performance Ranges for Building Factors

WWR - Southern Walls		**WWR - Northern Walls**		**WWR - Western Walls**		**WWR - Eastern Walls**	
Input	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh))**
0.95	9.39	0.95	3.28	0.95	11.93	0.95	9.38
0.8	7.42	0.8	2.43	0.8	9.69	0.8	7.52
0.65	5.45	0.65	1.58	0.65	7.46	0.65	5.66
0.5	3.54	0.5	0.98	0.5	5.06	0.5	3.88
0.4	2.26	0.4	0.57	0.4	3.47	0.4	2.69
0.3	0.99	0.3	0.17	0.3	1.87	0.3	1.5
BIM (20%)	0	BIM (18%)	0	BIM (16%)	0	0.15	0.13
0.15	-0.54	0.15	-0.09	0.15	0.03	BIM (13%)	0
0	-2.06	0	-0.35	0	-1.83	0	-1.24

Window Shades - South		**Window Shades - North**		**Window Shades - East**		**Window Shades - West**	
Input	**EUI ± (kWh)**	Input	**EUI ± (kWh)**	Input	**EUI ± (kWh)**	Input	**EUI ± (kWh))**
BIM	0	BIM	0	BIM	0	BIM	0
1/6 Win Height	-0.56	1/6 Win Height	-0.11	1/6 Win Height	-0.3	1/6 Win Height	-0.24
1/4 Win Height	-0.77	1/4 Win Height	-0.14	1/4 Win Height	-0.41	1/4 Win Height	-0.41
1/3 Win Height	-0.96	1/3 Win Height	-0.16	1/3 Win Height	-0.51	1/3 Win Height	-0.56
1/2 Win Height	-1.26	1/2 Win Height	-0.2	1/2 Win Height	-0.67	1/2 Win Height	-0.81
2/3 Win Height	-1.44	2/3 Win Height	-0.23	2/3 Win Height	-0.79	2/3 Win Height	-0.98

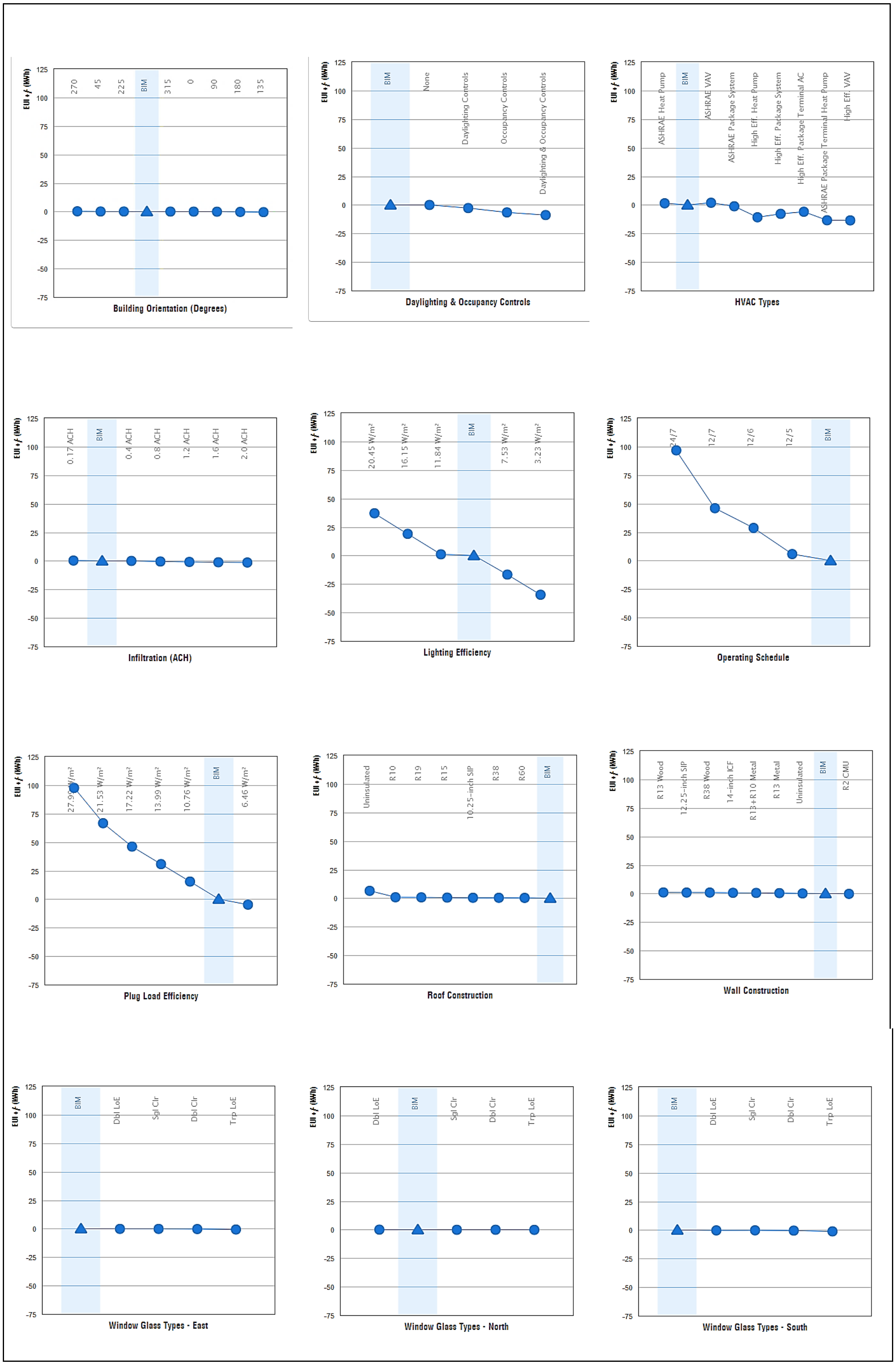
Window Glass Types - N		**Window Glass Types - S**		**Window Glass Types - W**		**Window Glass Types - E**	
Input	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh))**
Dbl LoE	-0.01	BIM	0	BIM	0	BIM	0
BIM	0	Dbl LoE	-0.34	Dbl LoE	-0.11	Dbl LoE	-0.18
Sgl Clr	-0.12	Sgl Clr	-0.29	Sgl Clr	-0.1	Sgl Clr	-0.2
Dbl Clr	-0.09	Dbl Clr	-0.54	Dbl Clr	-0.32	Dbl Clr	-0.32
Trp LoE	-0.18	Trp LoE	-1.21	Trp LoE	-1.01	Trp LoE	-0.73

Building Orientation (Degrees)		Operating Schedule		Roof Construction	
Input	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**
270	0.22	24/7	96.75	Uninsulated	6.42
45	0.04	12/7	45.98	R10	0.8
225	0.03	12/6	28.66	R19	0.71
BIM	0	12/5	5.72	R15	0.49
315	-0.02	BIM	0	10.25-inch SIP	0.36
0	-0.06			R38	0.34
90	-0.12			R60	0.25
180	-0.31			BIM	0
135	-0.52				

Wall Construction		HVAC		Infiltration	
Input	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**
R13 Wood	0.96	ASHRAE Heat Pump	1.4	ACH 0.17	0.27
12.25-inch SIP	0.88	BIM	0	BIM	0
R38 Wood	0.87	ASHRAE VAV	1.87	0.4ACH	-0.06
14-inch ICF	0.63	ASHRAE Package Syst.	-1.23	0.8ACH	-0.55
R13+R10 Metal	0.56	High Eff. Heat Pump	-10.83	1.2ACH	-0.93
R13 Metal	0.4	High Eff. Package Syst.	-7.85	1.6ACH	-1.23
Uninsulated	0.09	High Eff. Package Terminal AC	-6.01	2ACH	-1.43
BIM	0	ASHRAE Package Terminal Heat Pump	-13.45		
R2 CMU	-0.27	High Eff. VAV	-13.56		

Daylighting & Occupancy Controls		Lighting Efficiency		Plug Load Efficiency	
Input	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**	**Input**	**EUI ± (kWh)**
BIM	0	20.45 W/m²	37.09	27.99 W/m²	97.55
None	-0.06	16.15 W/m²	18.99	21.53 W/m²	66.62
Daylighting Controls	-2.79	11.84 W/m²	1.07	17.22 W/m²	46.11
Occupancy Controls	-6.59	BIM	0	13.99 W/m²	30.72
Daylighting & Occupancy Controls	-8.91	7.53 W/m²	-16.73	10.76 W/m²	15.45
		3.23 W/m²	-34.42	BIM	0
				6.46 W/m²	-4.82

Sensitivity analysis smartly helps to select the Energy Conservation Measures(ECMs) that have significant impact on the building energy performance and discard the factors with less impact. Moreover, by focusing on the important factors, the cost-effectiveness for intended proposed solutions. For example, the operating schedule of the school has a huge impact on total energy use, so improving this factor become significant to the analysis. On the other hand, the wall construction and glass type are much less critical and considering them in the analysis is waste of time and money. Figure 5.34. displays the relative range outcomes shown for each factor. Each building factor is represented by a chart, the values on the X-axis represent the input values from the rang of alternatives. Y-axis Values represent the impact on (EUI) in terms of the difference between EUI of the alternative and the EUI of as-built model. Chart with sharp curve indicates more sensitive factor and have more impact on the energy performance of the school. On the other hand, chart with mild curve has insignificant impact on the energy performance. Hence, its anticipated that the energy conservation measures (ECMs) for the school will be considered in this analysis context. Figure 4.7 illustrates Design Energy Factor Sensitivity outcomes relative to as-Built(BIM) value.



Building Orientation (Degrees)
270 45 225 BIM 315 0 90 180 135
Daylighting & Occupancy Controls
BIM None Daylighting Controls Occupancy Controls Daylighting & Occupancy Controls
HVAC Types
ASHRAE Heat Pump BIM ASHRAE VAV ASHRAE Package System High Eff. Heat Pump High Eff. Package System High Eff. Package Terminal AC ASHRAE Package Terminal Heat Pump High Eff. VAV
Infiltration (ACH)
0.17 ACH BIM 0.4 ACH 0.8 ACH 1.2 ACH 1.6 ACH 2.0 ACH
Lighting Efficiency
20.45 W/m² 16.15 W/m² 11.84 W/m² BIM 7.53 W/m² 3.23 W/m²
Operating Schedule
24/7 12/7 12/6 12/5 BIM
Plug Load Efficiency
27.99 W/m² 21.53 W/m² 17.22 W/m² 13.99 W/m² 10.76 W/m² BIM 6.46 W/m²
Roof Construction
Uninsulated R10 R19 R15 10.25-inch SIP R38 R60 BIM
Wall Construction
R13 Wood 12.25-inch SIP R38 Wood 14-inch ICF R13+R10 Metal R13 Metal Uninsulated BIM R2 CMU
Window Glass Types - East
BIM Dbl LoE Sgl Clr Dbl Clr Trp LoE
Window Glass Types - North
Dbl LoE BIM Sgl Clr Dbl Clr Trp LoE
Window Glass Types - South
BIM Dbl LoE Sgl Clr Dbl Clr Trp LoE

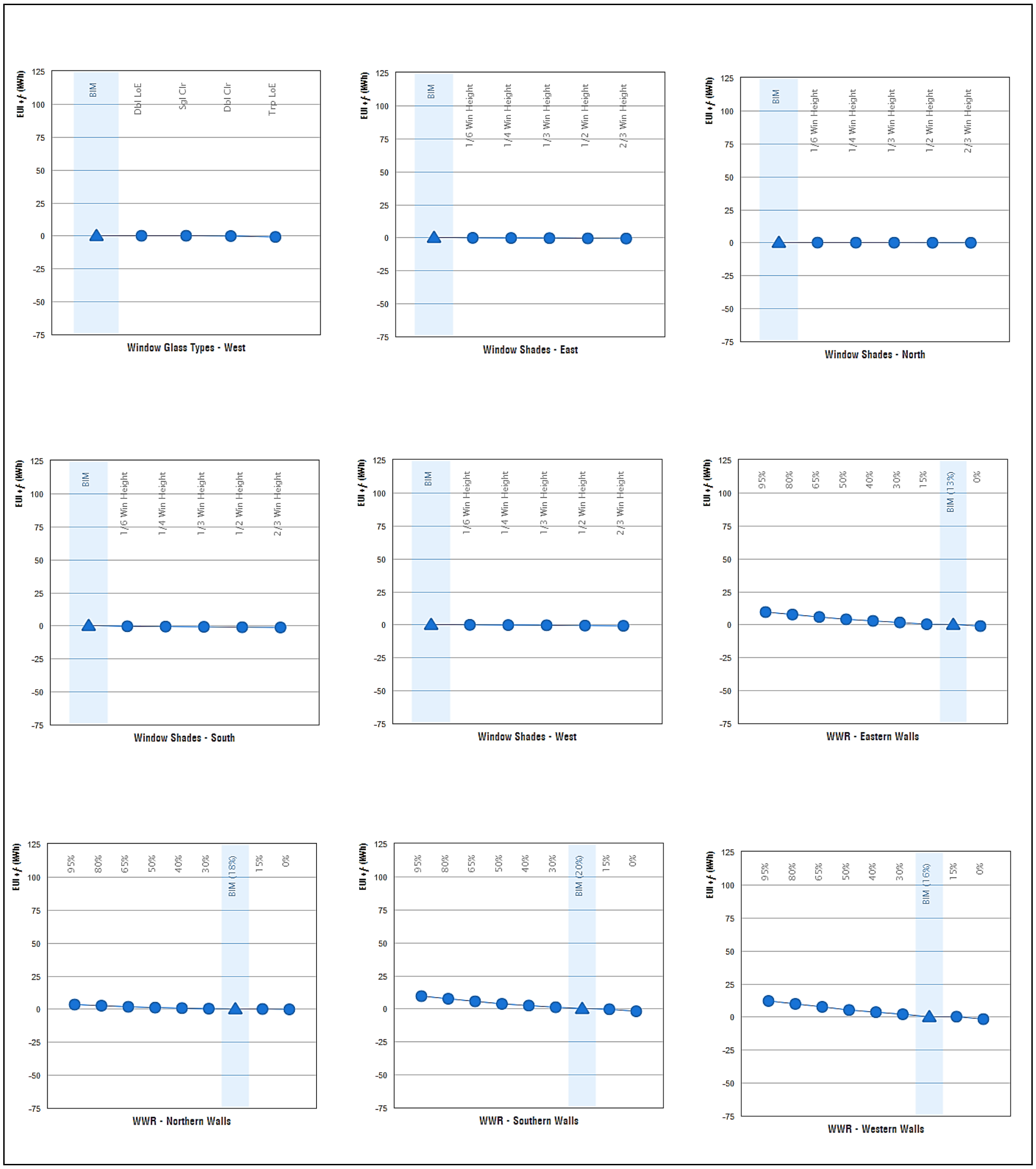


Figure 4. 7Building Factors Sensitivity outcomes.

Finally, it is very clear from the Sensitivity Analysis outcomes in Figure5.34 that Operating schedules, light efficiency. HVAC system and Plug Loads are the most critical to meeting EUI target and evaluate the potential towards Net Zero Energy Building School (NZEB).

CHAPTER 5

DEVELOPMENT OF THE NZEB SCHOOL MODEL

As described previously in chapter 3 and 4, the sensitivity analysis methodology provides an effective way of ranking building factors in terms of importance and impact. Since energy use in building is complex, simulation tool is used to model the total energy interactions between systems, elements, activities of occupants, and weather conditions. This is particularly important to have more realistic results that can be implemented. More than 246 simulations were conducted to find out the most sensitive factors in the reference building by applying different values of performance levels and see the impact on the EUI. The results are shown in figure 4.6. The Factors with straight curves have insignificant impact and have insignificant energy saving potential. The factors with sharp curves have a potential to yield high energy savings. Based on that, these factors are selected and will be used as measures in different NZEB scenarios and will be studied in this chapter.

5.1 Energy Conservation Measures (ECMs)

Energy Conservation Measures (ECMs) are the proposed alternatives that will be theoretically applied to school building to improve the EUI. As per the scoop of this thesis, ECMs will not modify the building geometry or shape. The ECMs scenarios were strategically set to (1) reduce energy demand in the school, (2) use very efficient system available in the market, (3) reduce plug loads and (4) cover remaining energy need with renewable energy. The following unit describes in detail (ECMs) that demonstrated high impact on energy performance energy through *sensitivity analyses* simulations.

The (ECMs) are proposed based on a number of industry resources including the Advanced energy design guide for K-12 school buildings: achieving zero energy (ASHRAE 2018) [9], U.S. Department of Energy guidelines [49], NREL's *Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector*[19], Illuminating Engineering Society, and industry's best practices.

This section describes the EEMs that are implemented in the advanced model.

All anticipated ECMs can be grouped into as following:

1. luminaire measures that reduce lighting Power Density(LPD) by using light emitting diode (LED) and cutting-edge automated lighting
2. Control strategies such as Wired versus Wireless Control, Dimming Control, Occupancy Sensors, Daylight Harvesting Sensors, Switches.
3. Plug load management such as using Energy-Efficient Equipment and controls.
4. HVAC strategies such as a high efficient heat pumps and a Ground-Source Heat Pump.

5.1.1 Electric Lighting Strategies

Lighting loads have a much larger impact in the school as analysis revealed previously. Moreover, cooling load in the school is mostly dominant than heating load, thus, inefficient lighting will not only use more energy to produce light, but it will add to the cooling load as well. In this section, the reduction of interior lighting energy use will be addressed by reducing lighting power density. can be reduced via the use of upgrading energy efficient lighting unites. The average Lighting power density (LPD) for the whole school is calculated for all space types according to the existing school condition. Most of light fixtures used in the school is mounted 40-watt fluorescent units with reflective fixture. Table 5.1 shows the Lighting power density (LPD) of the exist case and the energy efficiency alternatives.

Table 5. 1 Lighting Power Density Of the Exist Case and The Alternatives.

Input	EUI ± (kWh)
20.45 W/m²	37.09
16.15 W/m²	18.99
11.84 W/m²	1.07
As-built model (10.77)	0
7.53 W/m²	-16.73
3.23 W/m²	-34.42

Table 5.2 shows that the whole school the Lighting power density (LPD) can be reduced from 11.38 W/m² in the as-built model to 7.53 W/m² and even more to 3.23 W/m² in the advanced model. In the advanced model this mounted 40-watt fluorescent units with reflective fixture is replaced by light emitting diode (LED) fixture. Unlike fluorescent lambs, LED lamps can be dimmed to adapt with daylight harnessing, and it has longer life.

Table 5. 2 Lighting Power Reduction

	Lighting Power Density (W/m²)	**Energy Use Intensity** (kWh/ m² / year)
As-built model	11.38	134.00
Advanced Model (Low Efficiency)	7.53	117.64
Advanced Model (High Efficiency)	3.23	99.94

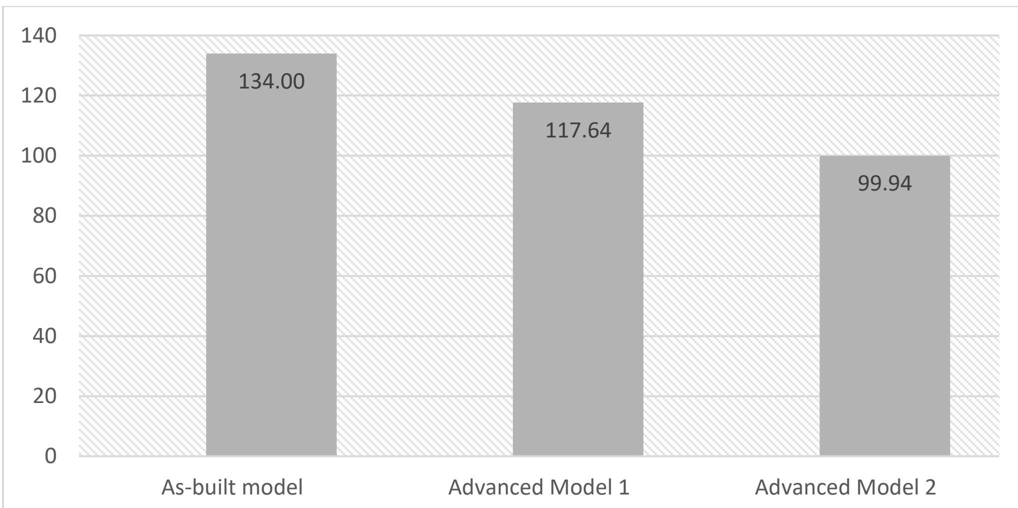


Figure 5. 1 Lighting Power Reduction

5.1.2 Lighting Controls

For school buildings, lighting is one of the main consumers of electric power. Thus, applying proper lighting strategies to decrease the energy use without compromising the comfort of the occupants is effective way to improve energy efficiency the school. Using the daylighting controls and occupancy sensors the lighting energy efficiency could be achieved.

5.1.2.1 Daylighting Controls

Daylighting controls can automatically adjust electric lighting levels according to the available daylight. Green Building Studio automatically allocate daylight sensors inside all building's spaces with access to daylight. The design setpoint of these sensors is 322 lux. This value is according to California Energy Commission's standards of applying daylighting control factors for classrooms. when daylight level is above the setpoint the electric lights in the space will automatically turned off [43]. For simulation, the as-built model, daylighting controls are off, one alternative run is simulated with daylighting controls ON. glazing properties and aperture placement are the same as exiting condition as illustrated on Table 5.3. with the associated properties

Table 5. 3 As-built glazing properties

Placement	**windows Type**	**Number Windows**	**Total Area** m^2	**U-value** **W / (m^2-K)**	**SHGC**	**Visible Light Transmission (VLT)**
All Windows	Single-glazed	132	316	5.75	0.86	0.90

5.1.2.2 Occupancy Sensors

Occupancy sensors use occupants motion in spaces to On/Off electric lighting units. Occupancy sensors can provide can provide substantial energy savings if used accurately. By reducing lighting energy demand the cooling energy demand will subsequently be decreased. This effect is being consider in the energy simulation. In the as-built model, occupancy controls are off. To test the effect of Occupancy Controls, one alternative run is simulated. According to ASHRAE 90.1[1] [9] [22] [29] the following values are applied in the simulations:

- Spaces less than 465 m^2, 15% reduction in lighting power density (LPD);
- Spaces greater than 465 m^2 – 10% reduction in LPD

The daylighting control and occupancy sensors alternatives in the advanced model include the following scenarios:

1. No Daylighting & Occupancy Control (as-built).
2. Only Daylighting Controls.
3. Only Occupancy Controls.
4. Daylighting & Occupancy Control.

Charts shown below are for the alternate runs daylighting & occupancy control and the associated energy use reduction Table 5. 4 and Figure 5.2.

Table 5. 4 EUI Reduction by applying daylighting & occupancy control.

	Lighting Power Density W/m²	Energy Use Intensity kWh/ m² / year
As-Built	11.38	134
Daylighting Controls	10.77	131
Occupancy Controls	9.85	128
Daylighting & Occupancy Control	9.33	125

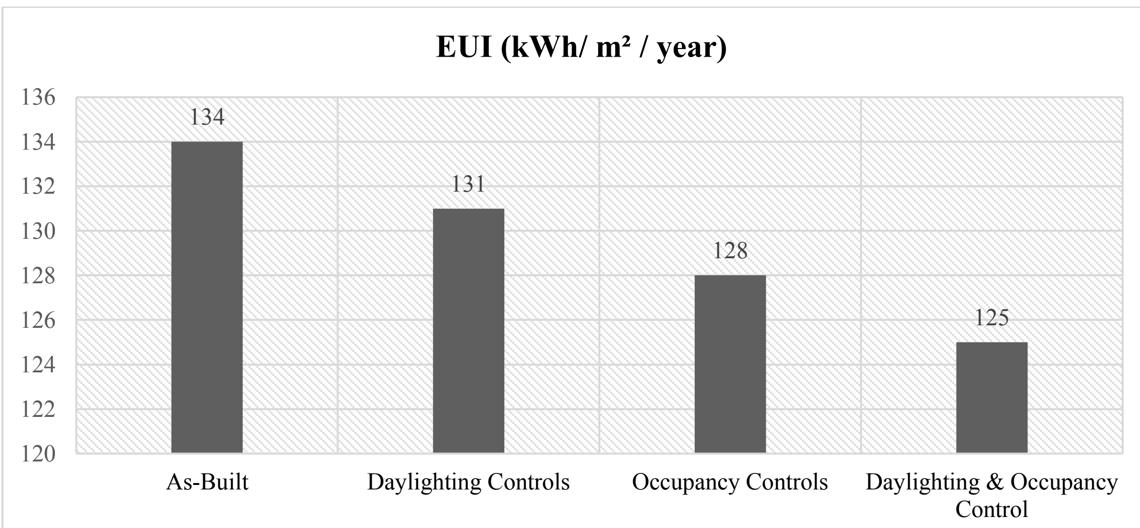


Figure 5. 2 Energy Use Reduction by applying daylighting & occupancy control.

5.2.3 Plug Loads

Plug loads in the schools uses up to 33% of total school's energy demand[16]. Plug loads includes all devices that are plugged into electric outlets in school. In the school as-built model, various plug loads accounts for 29% of total school energy use, they are also an additional cause of internal heat gains, resulting in more cooling loads. As-built model Average Equipment Power Density 7.59 W / m². Reducing this value will result in significant amount of total energy use in the school since the sensitivity analysis is high for plug load and it must play a significant role in achieving the goal net zero energy building. A realistic estimation of the possible reduction in plug load energy use requires careful study of school existing equipment, and the possible market alternatives high efficiency products. For the advanced model, a proposed list of high efficiency equipment was developed to reduce Plug Loads Density from 7.59 in as-built model to 6.46 in the advanced model. This reduction is significant step to achieve NZEB.

The high efficiency measures used in advanced model was collected as follows:

- Some equipment considered to be efficient and kept without changed.
- In simulation runs the Standards of California Energy Commission 2005 Building Energy Efficiency; Nonresidential Alternative Calculation Method (ACM) Manual, Table N2-2 [43].
- *ENERGY STAR rating* is found to be an acceptable reference for alternatives in the advanced model. if that item is not covered by the Standards of California Energy Commission [18] [43].

As-built model and advanced model Plug Loads and their associated reduction in energy use by applying high efficient equipment are summarized in Table 5.5. and Figure 5.3.

Table 5. 5 Plug Loads Reduction by Applying High Efficient Equipment.

	As-Built Model			Advanced Model		
Equipment	Qty	Rated Power Item (watts)	Plug Load (W)	Qty	Rated Power Item (watts)	Plug Load (W)
Desktop computer	44	65	2860.00	44	54	2376.00
Notebook computer	44	19	836.00	44	17	748.00
LCD Display	88	35	3080.00	88	24	2112.00
laser printer	3	215	645.00	3	180	540.00
Copy Machine	1	1100	1100.00	1	500	500.00
Refrigerator	3	76	228.00	3	65	195.00
Electric Stove (Cooking Range)	1	2200	2200.00	1	2200	2200.00
Microwave	1	1100	1100.00	1	1100	1100.00
Vacuum Cleaner	1	1500	1500.00	1	1340	1340.00
Coffee Machine	1	1100	1100.00	1	1100	1100.00
Tee Water Boiler	3	1500	4500.00	3	1200	3600.00
fax machine	1	170	170.00	1	50	50.00
overhead and digital projectors.	17	260	4420.00	17	250	4250.00
Drinking water cooler	6	120	720.00	6	120	720.00
Total Equipment Loads			**24459.00**			**20831.00**
Plug Loads Density W/m2			**7.59**			**6.46**

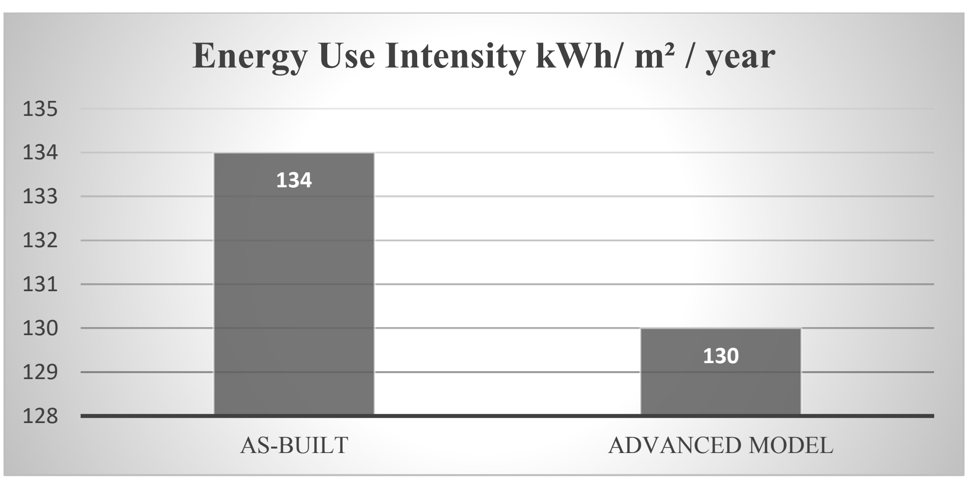


Figure 5. 3 Energy Use Reduction by applying high efficiency equipment.

5.2.4 HVAC SYSTEMS

Optimizing HVAC system design in zero energy school means maximizing the energy without compromising the quality of indoor environmental. It means (1) decrease solar heat gain, decrease equipment load, decrease electric light loads, and use of efficient cooling systems. One important aspect of zero energy school is the area availability for roof-mounted PV panels, thus, mechanical systems must be located properly to provide adequate space for solar panels. For this study, two HVAC systems that works in different technologies will be consider as follows:

1- An improved high efficient system similar to the exiting one, (Air to Air direct expansion mini-split system
2- Ground-source heat pump (GSHP) geothermal system.

5.2.4.1 GROUND-SOURCE HEAT PUMP

A GSHP system involves of internal heat pump inside building, an underground heat exchanger (pipes) in horizontal trenches or vertical wells to extract or sink heat to the earth and distribution system to deliver cooling or heating demands to indoor spaces[9]. The difference between GSHP horizontal trenches Figure 5.4 and vertical wells heat exchanger Figure 5.4 is shown bellow.

Figure 5. 4 Geothermal System Horizontal Trenches.

Source: (2018 ASHRAE AEDG).

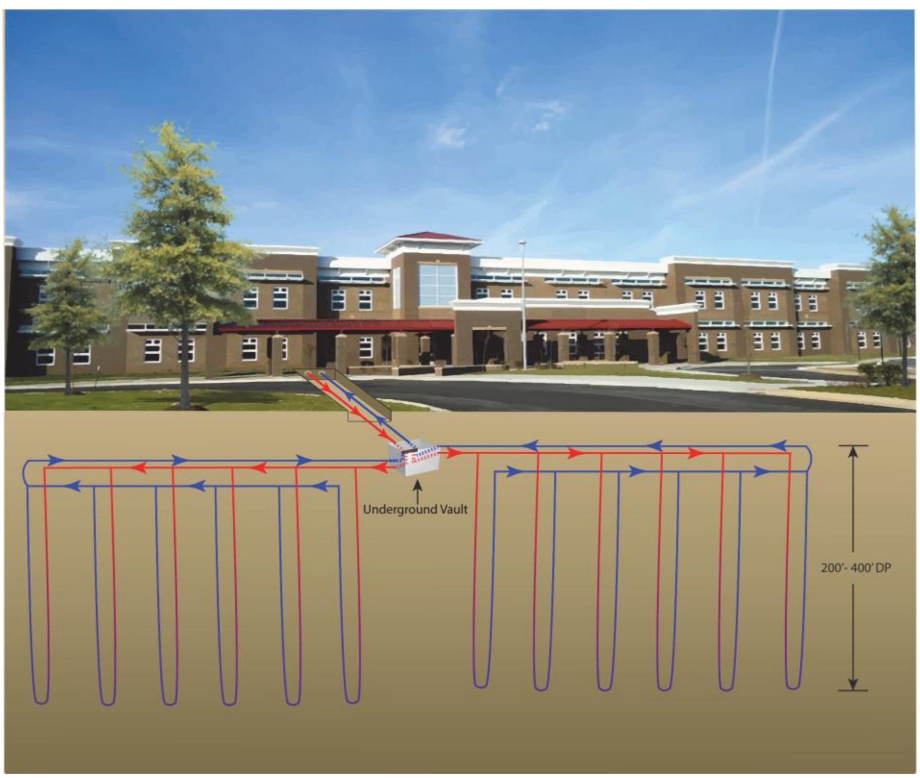


Figure 5. 5 Geothermal System Vertical Wells. [9]

A GSHP system has several more advantages when compared to a typical one. More efficient because it takes advantage of natural earth relative constant heat as source of energy, environment friendly since it's not using fossil fuel it reduces the green gas emissions (GGE), not using roof areas so it provides areas for solar panel systems, GSHP's elements are not exposed so they are protected against risk and vandalism, finally, GSHP system coast more in installation, but it can quickly pay back with lower operating cost.

GSHP Efficiency values are based on to ASHRAE/ARI/ISO Standard 13256-1:1998 (R2012) [2]. GSHP with cooling efficiency 18.0 EER and 3.7 COP for heating efficiency, an equivalent system in simulation process in order to figure out the energy use reduction resulting from increasing the efficiency of HVAC system. Table 5.6 and Figure 5.6 show the energy use reduction of two improved HVAC systems.

Table 5. 6 Reduction of EUI By Implying Two Improved HVAC Systems

	Efficiency SEER	**Efficiency HSPF/ cop**	**Energy Use Intensity kWh/ m² / year**
As-Built	12	7.7	134
HVAC Types High Eff. Heat Pump	14	8.2	124
GSHP	20.6	COP 3.7	121

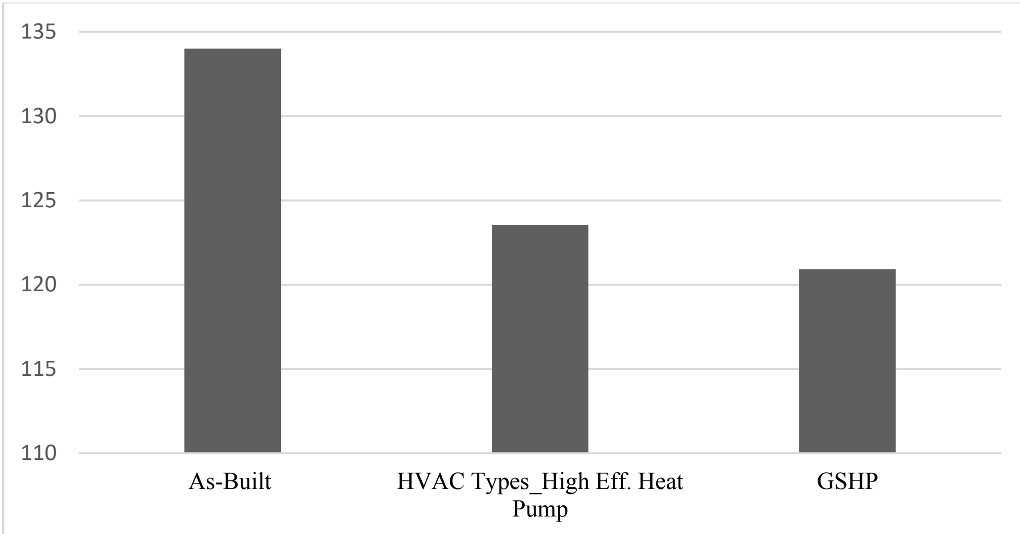


Figure 5. 6: Reduction on EUI due to implementation of HVAC alternatives

Note that, *Green building simulation engine currently* has no option to assigning ground-source heat pump system (GSHP) and cannot be modeled directly in the current version of *EnergyPlus*. The alternative reenable solution in this research is to model as ASHRE packaged heat pump, with exact cooling and heating efficiency. Thus, the make-up system will deliver reasonable and acceptable energy analysis outcomes as a model of the recommended inputs and outputs is configured.

5.3 Summary of Recommended Energy Conservation Measures

This part summarizes the recommended **ECMs** and the resulting **EUIs** in kWh/ m² / year described above. Table 5. 7 summarizes each factor and associated low to high-performance ranges for the selected ECMs on this study.

Table 5. 7 Summary of Recommended NZEB Energy Conservation Measures.

		Lighting Power Density (W/m²)		**EUIs** (kWh/m²/ year)
Electric Lighting	As-built model	10.77		134.00
	Advanced Model (Low Efficiency)	7.53		117.64
	Advanced Model (High Efficiency)	3.23		99.94
		Lighting Power Density (W/m²)		**EUIs** (kWh/m²/ year)
Lighting Controls	As-Built	11.38		134
	Daylighting Controls	10.77		131
	Occupancy Controls	9.85		128
	Daylighting & Occupancy Control	9.33		125
		Plug Loads Density (W/m²)		**EUIs** (kWh/m²/ year)
Plug Loads	As-Built	7.59		134
	Advanced Model	6.46		130
		Efficiency SEER	**Efficiency** HSPF/ cop	**EUIs** (kWh/m²/ year)
HVAC SYSTEM	As-Built	12	7.7	134
	HVAC High Eff. Heat Pump	14	8.2	124
	GSHP	20.6	COP 3.7	121

5.4 Solar Photovoltaics (PVs)

Photovoltaic (PVs) has become a main option that enables zero energy buildings to become more feasible. The cost of PV has dropped quickly in recent years due to wildly spread adaptations and developments in manufacturing [19]. In 2016 the total installed capacity of PV is more than 300GW with sharp increment in the latest years[24]. Therefore, schools souled consider take advantage of this sustainable source. PV panels produce direct current (DC) electricity using sunlight. DC is then converted to alternating current (AC), and it can be connected to the utility grid. Figure 5.7 shows various elements of PV system in a zero-energy school.

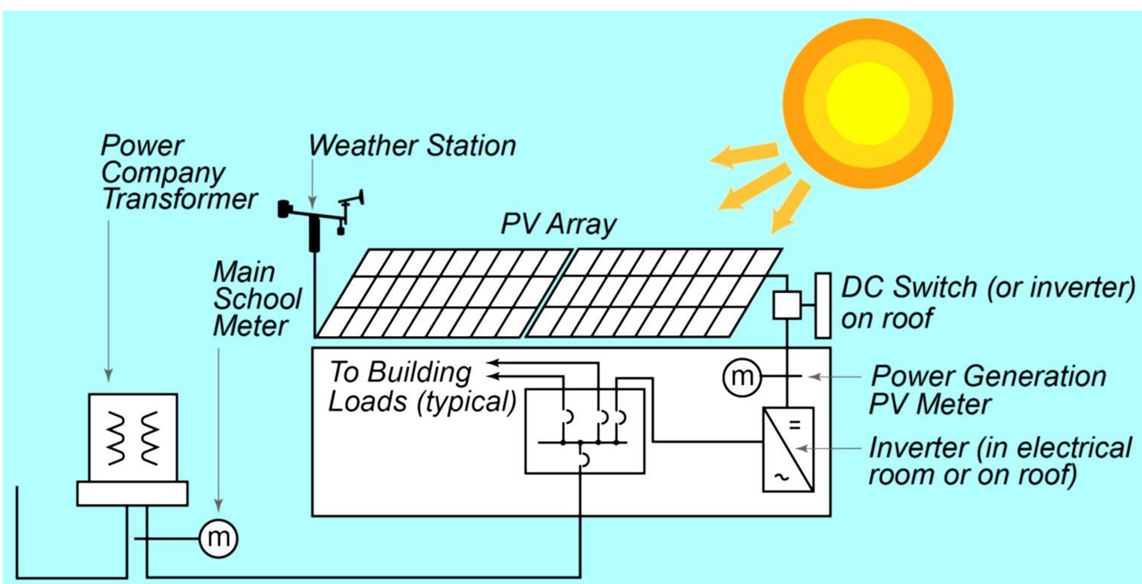


Figure 5.7: Typical PV System in A Zero-Energy School.

PV *Stand-alone system is the system* which is working independently without connection to utility grid, and mostly is used with battery storage for small buildings. PV *grid-tied systems* is the system working with connection to utility grid, this type is appropriate for schools and it can work without energy storage. *Net metering* is the difference between PV energy generation and energy consumption at the building. *Ground-mounted* PV panels are that fixed at ground level, usually fixed at about an angle of 30°, while roof mounted PV systems are fixed at around 10° angle [9].

5.4.1 PV Power Factors

The amount of energy produced by PVs depends on five main factors:

1. Incident solar radiation (insolation). The first step is to determine the possibility of installing solar PV panels in the location by calculating how much sunlight hits the studied location and this is known as incident solar radiation (insolation), and its measured in kWh/m2•year. Figure 5.8 illustrates the world map of Solar energy potential.

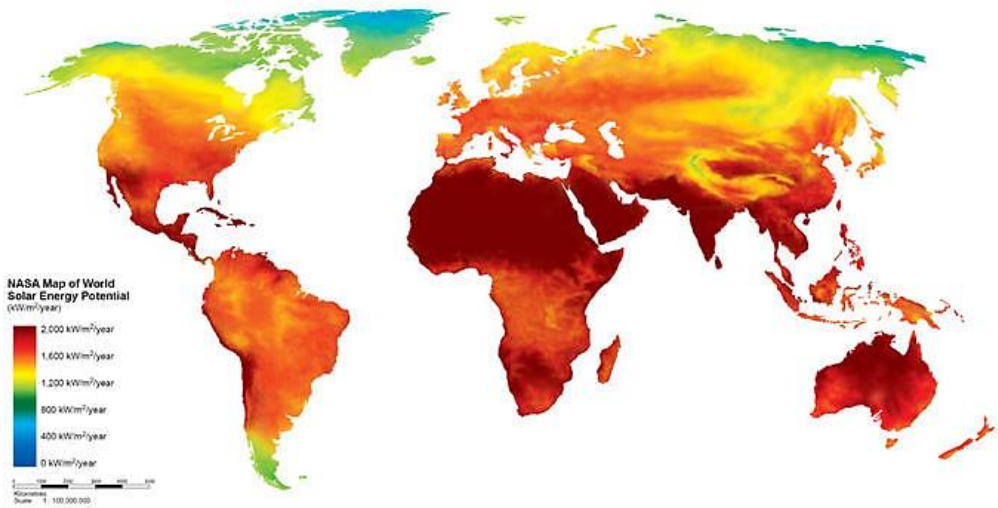


Figure 5. 8: The World Map of Solar Energy Potential [35]

2. The orientation and exposure of the panels to the sun. The more straight the sunlight hits on solar PV panels, the more energy they produce.

3. The efficiency of the panels. All roof surfaces in the model are assessed to see if the energy available (as determined by the geometry and the efficiency of the PVs panels) will be adequate within the desired payback period. Increasing PVs panels efficiency usually increase the capability of roof surfaces for placing PVs panels to achieve the desired payback period. On the other hand, decreasing PVs panel efficiency could result in elimination of some PVs roof panels in order to meet the payback limit.

4. The available roof area for PVs panels is the roof area that could be used for installing PVs panels after reduction of areas for roof equipment, maintenance access, and system structures.

5. Finally, The PV System losses. PVs power generation experiences losses due to convert DC power from the PV panels to AC power of building outlets Figure 5.9. These may result in increasing the capacity of PV system by 5 - 25% (NREL) [19]. Power conversion efficiency can be maximized by choosing an efficient inverter and other components and wiring panels together to avoid circuit imbalances due to some panels receiving full sun while others are shaded.

Figure 5. 9: Inside DC to AC Power PV Inverter (Source: Wikipedia)

5.4.2 On-Site PV Power Production

Autodesk's Green Building Studio(GBS) was used to analyses the potential PV performance on all roof surfaces of as-built model. The PV calculations performed by GBS were validated using the National Renewable Energy Labs (NREL) calculation methods. GBS uses rated system capacity in Photovoltaics for Utility Scale Applications Test

Conditions (PTC) not Standard Test Conditions (STC) watts which helps to design systems size correctly, and to more precisely estimate their performance. The available solar energy on the reference building site is illustrated in Table 5.8.

Table 5. 8 Site Solar Power Simulation Summary

Setting	**Description**
Building Energy Use Intensity (EUI)	134 kWh/m2/year
Cumulative Insolation	2,580,808 kWh/year
Peak Insolation	1353 kw
Average Insolation	560 kwh
Incident Solar Radiation (Insolation)	1853kwh/m2
Total roof area	1393 m2

The detailed analysis of the Photovoltaic (PV) is shown in Table 5.9, including the potentials for various options to produce electricity from solar panels. The simulation summary includes, different type of panel efficiencies, three options of areas coverage and the initial

Table 5. 9 Installed Panel Summary

Panel Efficiency Alternatives	Coverage Percent of total roof area	Initial Cost of The System	(EUI) kWh/m2/year	PV Energy Production KWh/year	PV Energy Offset		Energy Savings
16%	60 %	$372,765	49.5	272,493	159389	63%	$24,524
19%	60%	$461,862	35.7	316,773	115109	73%	$28,510
20%	60%	$575,350	26.2	347,429	84453	80%	$31,269
16%	75%	$466,190	31.0	332,039	99843	77%	$29,884
19%	75%	$580,158	14.2	385,996	45886	89%	$34,740
20%	75%	$720,128	2.6	423,350	8532	98%	$38,102
16%	90%	$565,643	14.4	385,580	46302	89%	$34,702
19%	90%	$705,968	-5.1	448,237	-16355	104%	$40,341
20%	90%	$876,051	-18.5	491,615	-59733	114%	$44,245

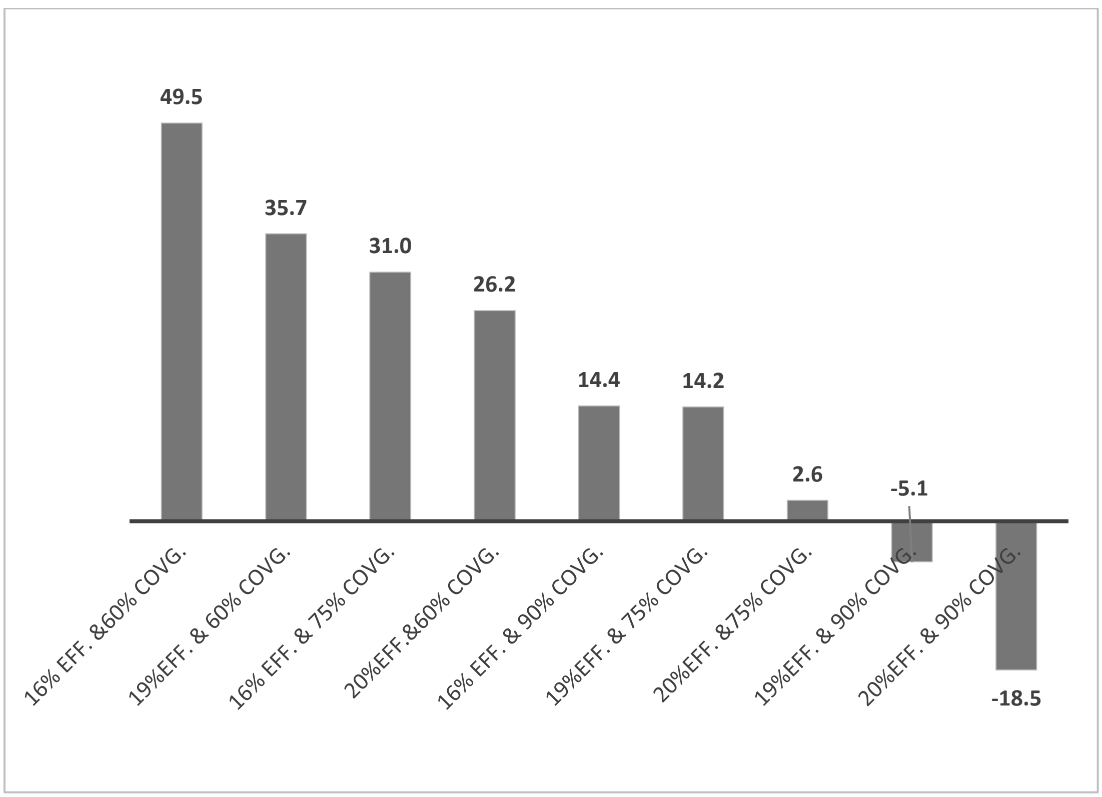


Figure 5. 10: Reduction in Energy Use Intensity (EUI) By Installing Only PV.

CHAPTER 6

RESULTS ANALYSIS AND DISCUSSION

As described previously in chapter 3 and 4, the sensitivity analysis methodology provides an effective way of ranking building factors in terms of importance and impact. Since energy use in building is complex, simulation tool is used to model the total energy interactions between systems, elements, activities of occupants, and weather conditions. This is particularly important to have more realistic results that can be implemented. More than 246 simulations were conducted to find out the most sensitive factors in the reference building by applying different values of performance levels and see the impact on the EUI. The results are shown in figure 4.6. The Factors with straight curves have insignificant impact and have insignificant energy saving potential. The factors with sharp curves have a potential to yield high energy savings. Based on that, these factors are selected and will be used as measures in different NZEB scenarios and will be studied in this chapter.

6.1 EUI Improvements from Energy Conservation Measures

In this section, these baseline building model will be used to develop the improved **EUI** by applying advanced energy conservation measures **(ECMs)** that were explained in the previous section in addition which can be summarized as follows:

- Lighting power density (LPD) was reduced 71% as LPD reduced from 11.38 (W/m^2) in As-built model to 3.23 W/m^2 in Advanced Model
- The Plug Loads Density (PLD) was reduced 15% as LPD reduced from 7.59 (W/m^2) in the As-built model to 6.46 (W/m^2) in Advanced Model.
- Adding day Lighting and occupancy Controls. occupancy controls added for classrooms, entrances, circulating paths, open and enclosed offices lights, active storage, restrooms and electrical/mechanical spaces. Daylighting control type Photo-sensor of lighting is response to daylight in spaces with access to light.
- Replace the heat pumps from packaged DX units to high-efficiency Ac units.
-

The resulting EUI s in (kWh/m^2/ year) from each ECM described above are shown in Table 6.1 and Figure 6.2.

Table 6. 1 Resulting EUI and Operating Cost by Applying ECMs To Baseline

	Baseline	Improved Plug Loads Performance	Improved Lighting Performance	Improved HVAC System	Adding day Lighting and occupancy Controls	Resulting EUI
EUI (kWh/ m²/ yr.)	134	130	102	90	85	85
Annual Energy cost (USD/ m²/ yr.)	9.67	9.33	6.9	6.08	5.53	5.53

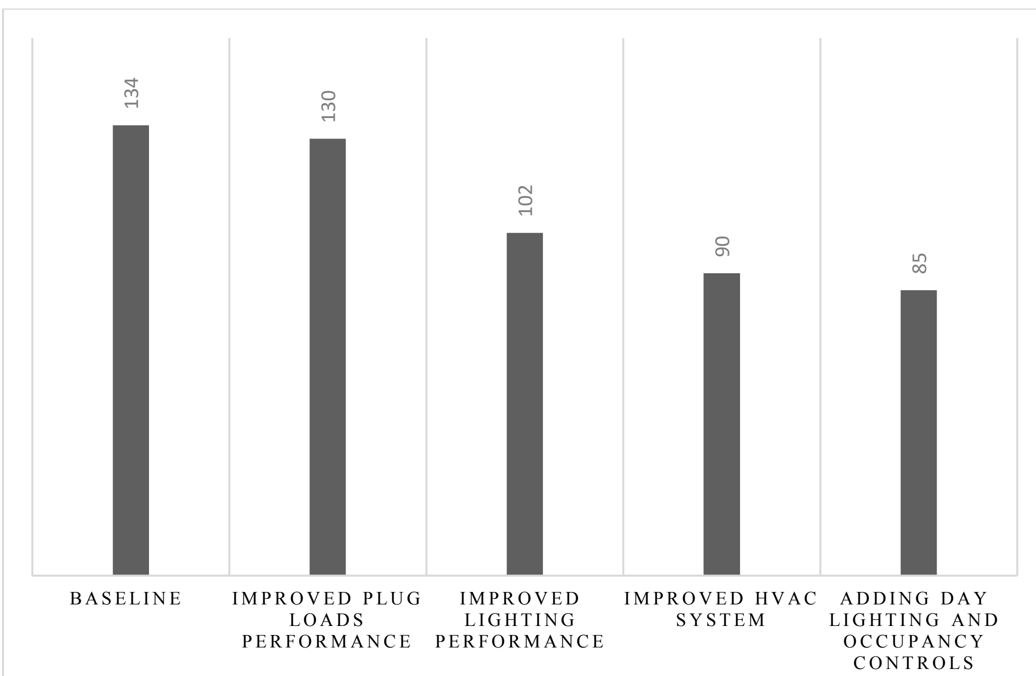


Figure 6. 1 The resulting EUIs in (kWh/m²/ year) by applying ECMs to Baseline.

6.2 Net Zero Energy Scenarios

The collection of all advanced ECMs can achieve 36.6% onsite energy savings for the school building, as illustrated in Figure 6.1 in terms of kWh/ m²/ year.). To study the feasibility of NZEBs in the school buildings, the use of a PVs system will be considered to cover the building demand of electricity.

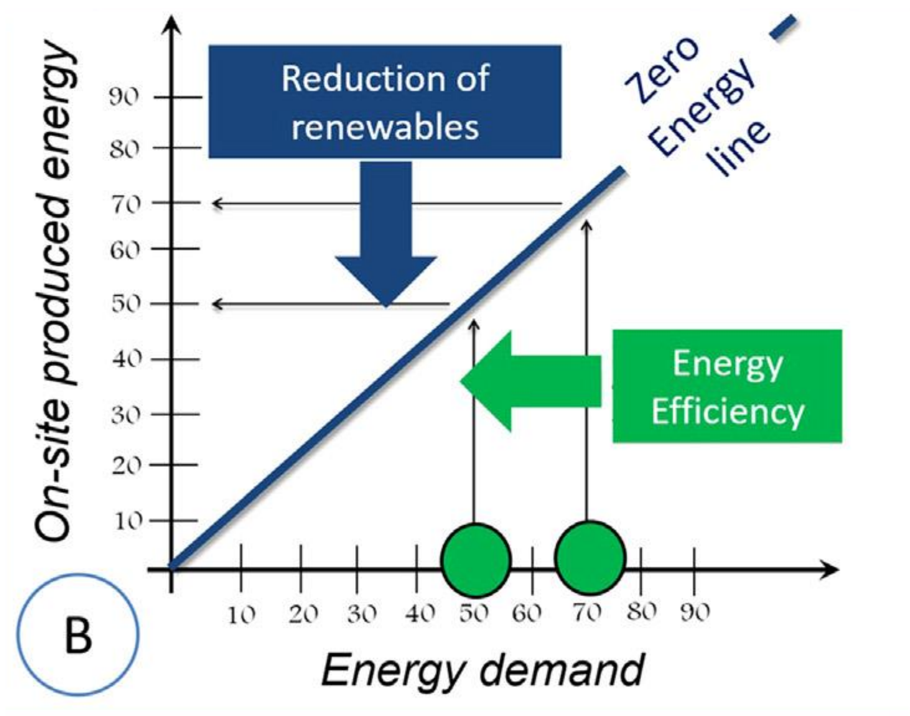


Figure 6. 2 A Concept of NZEB

A concept of NZEB, Net-Positive Energy Buildings and Net-Minus Energy Buildings is illustrated in Figure 6.2. By reducing the energy demand through the use of ECMs, the size of needed renewable energy is decreased as illustrated in Figure 6.3.

In this section, many NZEB scenarios will be considered as follows:

Base: is representing the characteristics of the existing school.

Scenario 1: Base with PV only to study the impact of applying PV to the Base. Two systems will be applied, PV panels with efficiency of 18.6% and 20.4 with an area equal to 90% of the total roof area of the school.

Scenario 2: to inspect what can be reached when Adding Day Lighting and occupancy Controls to the Base to reduce EUIs from 134 to 125 (kWh/m²/ year). This scenario includes installing rooftop PV panels to cover the remaining energy demand.

Scenario 3: Base with high efficient LED lamps. LPD levels were reduced from 10.77 to 3.23 (W/m²). This scenario includes installing rooftop PV panels to cover the remaining energy demand.

Scenario 4: applying a higher level of measures include Scenario 3 and Scenario 3 with rooftop PV panels to cover the remaining energy demand. The total energy reduction of applying ECMs is 316820 kwh/ year

Scenario 5: modeled an optimistic level of ECMs including: Improved AC System, Lighting Performance and Adding Day Lighting and occupancy Controls with total energy reduction of 285236 kwh/year. The remaining demand will be covered using PV panels.

Scenario 6: modeled of all ECMs with all the same measures as in Scenario 6 with high efficient plug loads the overall energy reduction is 273955 kwh/year.

Figure 5.13 illustrates all modeled scenarios and the associated annual energy reductions and the required on-site solar energy.

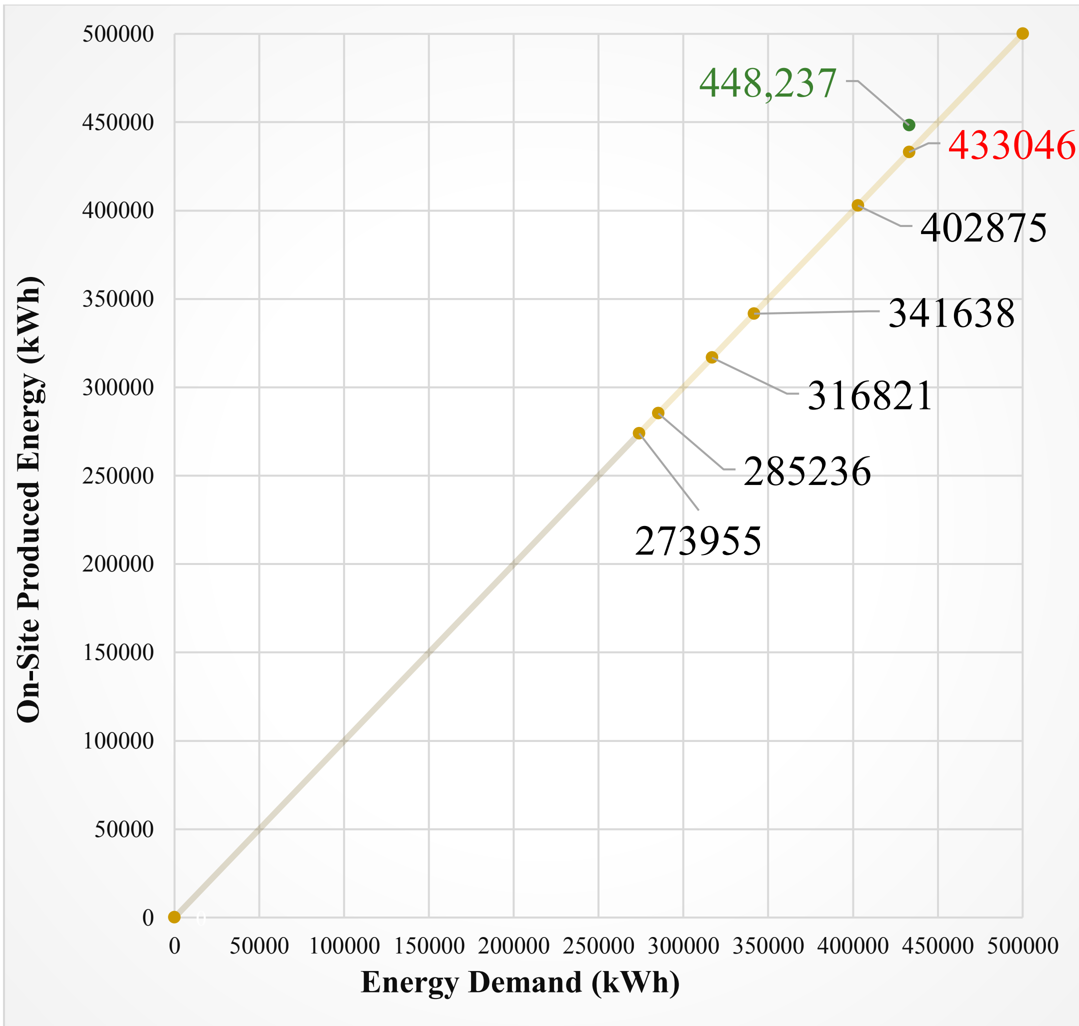


Figure 6. 3 NZEB Scenarios.

CHAPTER 7
COST-EFFECTIVENESS ANALYSIS

7.1 Background

Cost effectiveness of a system or alternative can be done through the Life cycle cost analysis (LCC) method. US DOE defines life-cycle costs as “the sum of all direct, indirect, recurring, nonrecurring, and other related costs incurred in the planning, design, development, procurement, production, operations and maintenance, support, and final disposition of real property over its anticipated life span for every aspect of the program, regardless of funding source.”[49]. life-cycle cost (LCC) is a tool that helps during the decision-making process to trad-off among different options. life-cycle cost (LCC) is a robust tool to evaluate the economic feasibility of a system or an asset. Other methods of measuring of cost-effectiveness alterative or systems includes; Simple Payback period(PBP), benefit/cost ratio (BCR) or Savings-to-Investment Ratios (SIR), Internal Rate of Return (IRR) and, present worth analysis or net present value (NPV), which take in account the time value of money. Generally, all cost-effectiveness methods give the same outcomes.

NIST has established guidelines for developing life-cycle cost (LCC) to evaluate the cost-effectiveness for energy management [37]. A systematic rule was established by the National Institute of Standards and Testing (NIST) has set terms and agreements standards for the whole building market. A software named Building Life Cycle Costing (BLCC), which based on the standards of NIST is used to develop LCC assessment, this tool was developed by NIST [37]. The general equation of Life Cycle Cost: sums the present value of all components.

LCC= Initial Investment Cost + PV replacement costs + PV residual value+ PV energy costs+ PV OM & R

future costs involve energy and non-energy (Operating maintenance and, replacement costs). To simply visualize the income and expenses of certain investment over a study period, its convenient to use the Investment Cash Flow Diagram Figuer7.1. Negative cash flows represented by downward arrows and positive cash flows is represented by upward arrows. The Present Value of money in the future can be calculated using the "*discount rate*" as following:

$P = F / (1 + i)^n$

where

F = future value (positive for incomes, negative for costs)

P = present value

i = discount rate

n = number of interest periods

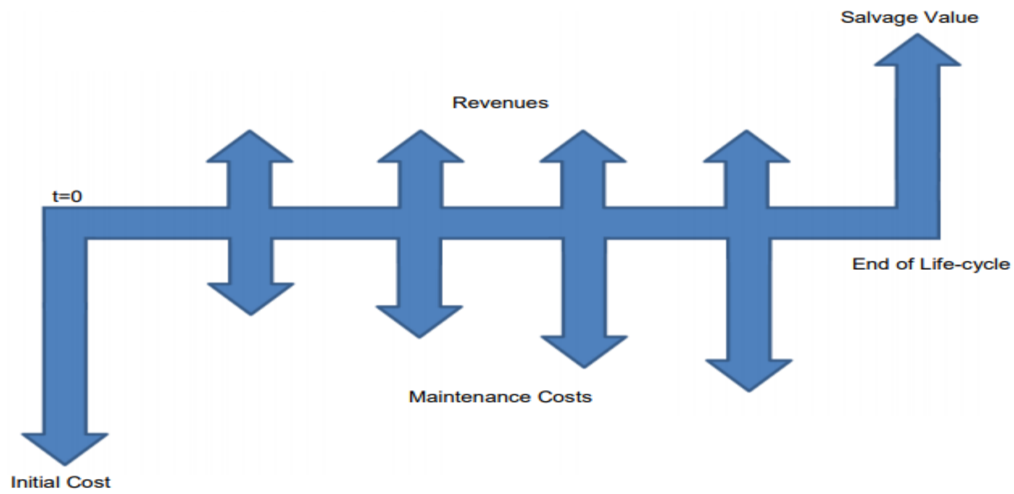


Figure 7. 1Cash Flow Diagram

NIST has established guidelines for developing life-cycle cost (LCC) to evaluate the cost-effectiveness as follows:

Step 1: Selection of nominal discount rate: this rate called Minimum Acceptable Rate of Return (MARR) is set by the investor and must be sufficiently acceptable to make the investor convinced to the new cash flow. If the investor borrows the investment required for applying energy measures, then, the loan rate should be the nominal discount.

Step 2: find the real discount rate by including the Inflation to the nominal discount rate equation (7.1).

$$d = \frac{1+D}{1+i} - 1 \qquad (7.1)$$

d= the "real" discount rate, exclusive of inflation

i= the assumed rate of general inflation

D= the assumed "nominal" discount rate

Step 3: Find the present value of all future costs including the inflation rate and time value of money.

Step 4: find the Present Value of future single costs using the Discounting Factor(SPV) equation (7.2).

$$PV = F_t \times \frac{1}{(1+D)^t} = P_o \times \frac{1}{(1+D)^t} \qquad (7.2)$$

Step 5: find the Present Value of future annually costs using the factor **of uniform Value (UPV)**, e.g., yearly operating costs equation (7.3).

$$PV = A_0 \times \frac{(1+d)^n - 1}{d(1+d)^n} \qquad (7.3)$$

PV = present value of the stream of annually recurring future costs of goods/services

A_0= annually recurring cost of goods/services in year 0 (assumed to change only due to inflation)

n= last year assumed in the analysis

d= the assumed discount rate (real)

Step 6: find the Present Value of future non-uniform expenses using the Factor of Modified Uniform Present, e.g., annual future utility costs that escalate at a uniform rate

7.2 Life Cycle Cost Analysis

The life cycle cost analysis is best approach to evaluate alternatives by observing outside initial costs. The analysis considered a net present value (NPV) based on LCCA method established by the Federal Energy Management Program (FEMP) (NIST 1995). was conducted based on the Federal Energy Management Program (FEMP) LCCA procedure (NIST 1995). One assumption is excluded from the FEMP procedure which is the use of study period), a 30-year time horizon is used rather than the given 25 years. The 30-year is suggested by the ASHRAE 90.1 standards [46] and it is commonly used for conducting LCCA in government and industry as well. a Discount rate of 6% is chosen based on different literature review such as National Institute of Standards and Technology(NIST), The 2018 real discount rate for public investment and regulatory analyses published by Office of Management and. Budget (OMB) and by consulting local expertise[49]. Latest electricity energy costs of $0.085/kWh for public sector is taken from the Saudi Electricity Company (SEC) Website. Energy cost escalation for governmental sector in SA hasn't changed for long time, hence, 0% differential price change is assumed in LCCA calculation. Table 7.1 summarizes the criteria for LCC analyses in this study. Estimating the operating and maintenance cost are basically the same for all alternative in the same project, so they are not included in LCCA [37].

Table 7. 1 Summary of the criteria for LCC analyses.

Criteria for Economic Analysis	**Methodology and Parameters**
Evolution Method	Life-cycle cost analysis
Discounting Approach	Present Value at the base date
Cost Measurement Basis	Constant dollars as of the base date
Cash-Flow Convention	End-of Year cash flows or when incurred
Evolution Criteria	Lowest life cost
Base Date	Beginning of study period (2018)
Study Period	30-year service period.
Discount Rate	A real rate of 6%
Energy Prices	Local electricity price of governmental sector $0.085/kWh
Cost Escalation	0% differential price change is assumed in LCCA calculation

7.3 Basis for Incremental Costs of Energy Efficiency Measures

The costs used in this thesis aim to set a reasonable estimate of the incremental costs for the proposed ECMs recommended for NZEB school based on analysis results of the as-built energy simulations. Table 7.2 summarizes the methods and sources used to calculate the incremental costs. Incremental costs for the ECMs are calculated based on the difference between the costs for the as-built measure and the costs for ECMs. The incremental costs are divided into two types: (1) incremental costs for Energy Conservation Measures, based on a per unit cost and (2) costs for acquisition and installation of PVs system. Costs are founded for the as-built and the ECMs used in the school, and then the ECMs costs are summed to get the total cost for the advanced model.

Table 7. 2The Basis Used to Calculate the Incremental Costs ECMs Costs

Component	Cost Calculation Method	Source
Electric Lighting	Incremental cost (difference between the cost for the as-built measure and the cost of advanced measure)	Cost provided from at least four local four manufacturers.
Lighting Controls	Incremental cost (difference between the cost for the as-built measure and the cost of advanced measure)	ASHRAE 90.1 Cost-effectiveness study and consulting local market
Plug Loads	Incremental cost of high efficient equipment	On-line sources such as EnergyStar NREL, and others
Heat Pumps	Cost of advanced system minus cost of baseline system. Multiplied by existing units number	Cost provided from at least four local four manufacturers.

7.3.1 Cost Analysis – Advanced Electric Lighting

The bottom line for applying advanced lighting alternative is to reduce lighting power density (LPD) without compromising the needed illuminance level in a space. Therefore, using LED lighting fixture that produced the required lighting level at a lower electricity consumption. Using LED with higher efficiency will result in reduction of the cooling loads that are produced by lighting fixtures. Therefore, all lighting fixtures are replaced by LED type lamps with an 50000-hour rated life. According to the Ministry of Education the yearly academic calendar involves 167 studying days with 9 hours/day (1503hour/year). The cost analysis of advanced electric lighting is calculated using the net present value (NPV) and is illustrated in Table 7.3. The annual electricity reduction due to applying efficient lightings is difference between base line annual electricity cost and advanced model Which is 109775.4 (KWh). The relevant cash flows as:

- **$4072.4** Incremental Initial Investment costs, assumed to occur in lump sum at the base date. Appendix B for the total calculations.
- **$0** Replacement cost for a lamb unit at the end of service period(33years).
- **$0** Residual value at the end of 30-year study period
- **$0** Annual Operating and Maintenance (O&M) costs or savings.
- **$ 9331** Annual electricity cost

Table 7. 3: Data Summary for NPV incremental cost for Lighting Alternative

Cost Item	Base Date cost	Year of Occurrence	Discount Factor		Present Value
Incremental Initial cost	4072	Base date	already in present value		4072
Capital replacement (lamp)	0	33	SPV_{30}	0.1741	0
Residual value	0	33	SPV_{30}	0.1741	0
Electricity cost 109775.4 KWh at $0.085)	9331	Annual	UPV_{30}	13.7648	128439
OM&R	0	Annual	UPV_{30}	13.7648	0
Total LCC					**$132511**

- Single Present Value
- Uniform Present Value

7.3.2 Cost Analysis – Advanced Plug Loads

For the Plug Loads reduction measure, all students and staff computers were replaced with Energy Star rated units. Al other loads were replaced by high efficient measures as illustrated in table 5.99. The incremental initial cost of all the equipment used was calculated to be \$8.73/m2. The rated life of the equipment was estimated to be 10 years and the maintenance cost was not calculated and assumed to be similar for base and advanced cases. Using the general role of thump for the residual value at the end of service periods was calculated using the linearly prorating its initial cost. The cost analysis of advanced plug loads is calculated using the net present value (NPV) and is illustrated in Table 7.4. The annual electricity reduction due to applying efficient plug loads is the difference between base line annual electricity cost and advanced model Which is 12892 **(**KWh). The relevant cash flows:

- **\$28,152** Incremental Initial Investment costs.
- **\$28,152** Replacement cost at the end of service period(10years).
- **\$2815** Residual value at the end of 10-year service period
- **\$0** Annual Operating and Maintenance (O&M) costs or savings.
- **\$ 1096**Annual electricity cost

Table 7. 4: Data Summary for NPV incremental cost for Plug Loads Alternative

Cost Item	Base Date cost	Year of Occurrence	Discount Factor		Present Value
Incremental Initial cost	28,152	Base date	already in present value		28152
Capital replacement (equipment)	28,152	10	SPV_{10}	0.5584	15720
Capital replacement (equipment)	28,152	20	SPV_{20}	0.3118	8778
Capital replacement (equipment)	28,152	30	SPV_{30}	0.1741	4901
Residual value (equipment)	-2815	10	SPV_{10}	0.5584	-1572
Residual value (equipment)	-2815	20	SPV_{20}	0.3118	-878
Residual value (equipment)	-2815	30	SPV_{30}	0.1741	-490
Electricity cost (12892 KWh at $0.085)	1096	Annual	UPV_{30}	13.7648	15086
OM&R	0	Annual	UPV_{30}	13.7648	0
Total LCC					**$69698**

7.3.3 Cost Analysis – Advanced Daylighting & Occupancy Control

The cost of this measure is estimated to be $27.09/m2 and this cost is taken according to the ASHRAE 90.1 Cost-effectiveness methodology (Thorton et al, 2013). The cost includes installation and materials of: infrared, ultrasonic sensors, fixtures and the dimmable ballasts. The contracting cost of the controls is assumed to be 5% of the system cost. And the service life is assumed to be 15 years. The overall area of perimeter places that can use from the controls is calculated to be 1206 m^2; the corridors, stairways, the atrium, restrooms and the other inactive zones were excluded. Table 7.5 shows the cost analysis of the advanced controls is calculated using the net present value (NPV). The annual electricity reduction due to applying efficient lightings is the difference between base line annual electricity cost and advanced model Which is 12892 **(**KWh). The relevant cash flows:

- **$32,670** Incremental Initial Investment costs,
- **$1634** The contracting cost of the controls
- **$32,670** Replacement cost at the end of service period(15years).
- **$2178** Residual value at the end of 10-year service period
- **$327** Annual Operating and Maintenance (O&M) costs or savings.
- **$ 2466** Annual electricity cost

Table 7. 5: Data Summary for NPV incremental cost for controls Alternative

Cost Item	Base Date cost	Year of Occurrence	Discount Factor		Present Value
Initial Incremental cost	32,670	Base date	already in present value		32670
contracting cost of the controls	1,634	Base date	already in present value		1634
Capital replacement (controls)	32,670	15	SPV_{15}	0.4173	13633
Capital replacement (controls)	32,670	30	SPV_{30}	0.1741	5688
Residual value (controls)	-2178	15	SPV_{15}	0.4173	-909
Residual value (controls)	-2178	30	SPV_{30}	0.1741	-379
Electricity cost (29007 KWh at $0.085)	2466	Annual	UPV_{30}	13.7648	33944
OM&R (1%) of initial cost	327	Annual	UPV_{30}	13.7648	4501
Total LCC					**$90782**

7.3.4 Cost Analysis – Advanced Air Conditioning

The alternative Air conditioning system is high efficiency heat pump(HP), is also analyzed for cost effectiveness. Incremental costs are calculated using the difference between the current HP unite cost and the cost of the advanced measure described previously in energy conservation measures in Section 5. The incremental initial costs are summarized elaborated in Appendix B. The costs listed below are taken directly from local marketplaces, contractors and the maintenance department in MOE. Summary for NPV incremental cost analysis for advanced Air Conditioning Alternative is shown in Table 6.6. The annual electricity reduction due to applying efficient HP unites is the difference between base line annual electricity cost and advanced model Which is 41899 (KWh). The relevant cash flows:

- **$118620** Incremental Initial Investment costs
- **$23724** Capital replacement cost of the (year20)
- **$118620** Replacement cost for an equipment unit at the end of service period(25years)
- **$4745** Residual value at the end of 25-year service period
- **$0** Annual incremental O&M costs or savings
- **$ 3561** Annual electricity cost

The results of this analysis are outlined in **Table7.6** below.

Table 7. 6: Data Summary for NPV incremental cost for AC Alternative

Cost Item	Base Date cost	Year of Occurrence	Discount Factor		Present Value
Incremental Initial installment cost	118,620	Base date	already in present		118620
Capital repair replacement	23,724		SPV_{20}	0.3118	7397
2nd Incremental Initial installment cost at beginning of service period	118,620	33	SPV_{25}	0.233	27638
Residual value (equipment)	-4745		SPV_{25}	0.233	-1106
Electricity cost 12892 KWh at $0.085	3561	Annual	UPV_{30}	13.7648	49016
OM&R	0	Annual	UPV_{30}	13.7648	0
Total LCC					**$201566**

7.3.5 PVc Cost Analysis

A value of \$8.00 is an estimated cost/watt of rated system capacity, for materials and labor to install a complete grid-connect solar electric system. This estimated cost is based on research conducted at the Department of Energy's Lawrence Berkeley National Laboratory (LBNL) ("Tracking the Sun: The Installed Cost of Photovoltaics in the U.S. from 1998-2007," by Ryan Wiser, Galen Barbose, and Carla Peterman) that studied 37,000 grid-connected PV systems and found that average installed costs per rated watt is \$7.60 in 2007. The Utility rate for governmental sector in Saudi Arabia is flat and is \$0.085(0.32SR). The PV simulation-based analysis summary using different types of PV panels. is illustrated in Figure 6.12. -6.14. These types are fairly representing the performance of the common practices available on marketplace. The system was also assumed to be connected to the grid and did not include battery. The maintenance cost is assumed to be 0.1%of installed cost.

Three types of PV panel are used in the analysis. Thy fairly represent the common practices of the existing technologies today. These panels have different levels of efficiency. Choosing one type against another will result in different cost and potential electrical energy outputs. **Table 7.7** summarizes the cost analysis of the three types of PV panel as well as the energy output. The LCC is calculated using the net present value (NPV).

Table 7. 7: PV Systems Net Present Value analysis

Panel Alternatives	Cost per Installed Watt	initial cost of the System	(EUI) kWh/m2/year	PV Energy Production KWh/year	PV Energy Offset	Energy Savings	Payback period years	O&M	NPV
16% Eff & 60 covg.	2.86	$372,765	49.5	272,493	63%	$24,524	15.2	$3,728	$86,507
16% Eff & 75 covg.	2.86	$466,190	31	332,039	77%	$29,884	15.6	$4,662	$119,013
19% Eff & 60 covg.	3.06	$461,862	35.7	316,773	73%	$28,510	16.2	$4,619	$133,002
16% Eff & 90% covg.	2.86	$565,643	14.4	385,580	89%	$34,702	16.3	$5,656	$165,837
19% Eff & 75% covg.	3.06	$580,158	14.2	385,996	89%	$34,740	16.7	$5,802	$181,826
20% Eff & 60 covg.	3.47	$575,350	26.2	347,429	80%	$31,269	18.4	$5,754	$224,134
19% Eff & 90% covg.	3.06	$705,968	-5.1	448,237	104%	$40,341	17.5	$7,060	$247,857
20% Eff & 75% covg.	3.47	$720,128	2.6	423,350	98%	$38,102	18.9	$7,201	$294,786
20% Eff & 90% covg.	3.47	$876,051	-18.5	491,615	114%	$44,245	19.8	$8,761	$387,614

7.3.6 Cost Analysis – Net Zero Energy Scenarios

As pointed out in the previous chapter, different NZEB scenarios were proposed based on the sensitivity analyses. In order to achieve NZEB goal, PV panels must be implied to offset the remaining energy demand after using ECMs. In this section, the cost-effectiveness of the different scenarios will be calculated based on the simulation results and the initial costs that have been mentioned earlier in this chapter to reach the lowest cost one in term of net present value (NPV).

Scenario 1: in this scenario only PV panels with efficiency of 18.6% with an area equal to 90% of the total roof area of the school was applying PV to the Base without adding any ECMs. The NZEB goal is reached and achieved a surplus. The LCC net present value (NPV) of this scenario is $247,857.

Scenario 2: Adding Day Lighting and occupancy Controls to the Base to reduce energy consumption from 433046 to 402875 (kWh/year). This scenario includes installing rooftop PV panels with efficiency of 18.6% with an area equal to 75% of the total roof area of the school to cover the remaining energy demand. The life cycle cost NPV of this scenario is the sum of NPV of ECM measure and NPV of installed that is: $385,568.

Scenario 3: Base with high efficient **LED lamps.** LPD levels were reduced from 10.77 to 3.23 (W/m^2). This scenario includes installing rooftop PV panels to cover the remaining energy demand with efficiency of 18.6% with an area equal to 60% of the total roof area of the school to cover. Energy reduce consumption from 433046 to 341638 (kWh/year). The life cycle cost NPV of this scenario is the sum of NPV of ECM measure and NPV of installed and equals to $356,645.

Scenario 4: applying a higher level of measures include Scenario 2 and Scenario 3 with rooftop PV panels with efficiency of 18.6% with an area equal to 60% top roof area to cover the remaining energy demand. The total energy reduction of applying ECMs is 316820 kwh/ year. The life cycle cost NPV of this scenario is the sum of NPV of ECM measure and NPV of installed and equals to $356,295.

Scenario 5: modeled an optimistic level of ECMs including: Improved AC System, Lighting Performance and Adding Day Lighting and occupancy Controls with total energy reduction of 285236 kwh/year. The remaining demand will be covered using PV panels with efficiency of 16% with an area equal to 75% top roof area. The life cycle cost NPV of this scenario $543872

Scenario 6: modeled of all ECMs with all the same measures as in Scenario 5 with high efficient plug loads the overall energy reduction is 273955 kwh/year PV panels with efficiency of 16% with an area equal to 75% top roof area. The life cycle cost NPV of this scenario equals to $581064

The life cycle cost present value of scenario 1 (the Base with PV system) displays that efficiency enhancements make the NZEB target much more achievable. Adding rooftop PV panel to school buildings make it possible to reach NZEB. But when ECMs are also added, the building energy performance increases but the LCC cost increases too which make it more expensive to reach ZEB than could with only PV system. Table 7.8 shows the result of LCC analysis of all scenarios.

Table 7. 8 Net Present Value Net Zero Energy Scenarios.

Scenarios #	NZEB Measures	NPV
Base	Reference Building	NA
Scenario1	Only PV system	$247,857
Scenario 2	Adding day Lighting and occupancy Controls	$385,568
Scenario 3	Improved Lighting Performance	$356,645.
Scenario 4	Improved Lighting Performance and Adding Day Lighting and occupancy Controls	$356,295
Scenario 5	Improved AC System, Lighting Performance and Adding Day Lighting and occupancy Controls	$543872
Scenario 6	All ECMs	$581064

The Annual uniform worh is an important meatod to measure the cost-effectiveness of alternatives or systems and can be calculated using the following (7.4):

$$AW = PW * F \qquad (7.4)$$

Where, AW= Annual Worth, PW= Present Worh , and F = Capital Recovery Factor

Taking the present worth values in Table 7.8 and using the equation above to find annual worth and then divide the result by the annual electricity use in KWh to find the cost of each scenario per KWh. An Excel spreadsheet was used for the calculations and the results are shown the following Table 7.9. Scenarios from 1 to 4 has less cost per KWh than the base case and scenarios 5 and 6 has more cost per KWh thab the current sitiations.

Table 7. 9: Annual worth and unit cost of each scenario

Scenario #	**Annual Energy Use (kWh/year).**	**Incremental Initial cost**	**PW**	**AW**	**Cost per KWh**
Scenario1	433046	$705,968	$247,857	$17,994	0.042
Scenario 2	402875	$670,940	$385,568	$27,992	0.069
Scenario 3	341638	$594,373	$356,645	$25,892	0.076
Scenario 4	316820	$685,155	$356,295	$25,867	0.082
Base	433046	$0	$506,667	$36,784	0.085
Scenario 5	285236	$891,049	$543,872	$39,485	0.138
Scenario 6	273633	$960,747	$581,064	$42,185	0.154

CHAPTER 8

CONCLUSIONS AND FURTHER RESEARCH

The study of net zero energy school in this thesis is the first of its kind on Saudi Arabia. This study revealed the challenges connected with achieving net zero school building in mild areas of Saudi Arabia and laid the ground for more investigations in NZEB in schools in future.

A Typical public school in Abha City area that represent most of governmental school in the mild climatic areas in Saudi Arabia, has been studied with diverse detailed simulations with the aim of quantify all the available characteristics of the building, in order to identify the most appropriate improving solutions to reduce the energy use and achieve NZEBs to the available school design. This study has verified how the sensitivity analysis methodology can be used to identify the most critical factors in the building that has the significant impact on energy performance and it helps to narrow down the possible scenarios, and moreover it will result in more cost-effective alternatives. The comprehensive analysis of the school building led to the formulation of suggestions for improving the energy performance. Performed calculations have uncovered that it is conceivable to lower the energy demand down to from 134 to 85 kWh/m2 year, for by improving the efficiency of Lighting lamp, lighting controls, and plug loads and by replacing existing HVAC systems by high performance system. Both improving efficiencies of active systems and the utilization from renewable energy sources are necessary to reach NZEBs. The Net Zero Energy School buildings of the selected region cities is thus proved to be a technically and economiccaly feasible on life cycle cost prespective. The methodology included cost effectiveness analysis considering the life cycle cost present value to investigate among the proposed scenarios to find out the optimized one that can achieve the NZEB goal with the lest cost among these scenarios. An estimate of the additional cost required to achieve different levels of energy performance compared to a baseline and helped to conduct life cycle cost analysis of the proposed measures to determine more reliable economic feasibility on long run. In Such types of analysis can be used to convince owners to agree to higher initial costs, but less energy cost since they would lead to larger savings during the building life cycle. In this study adding PV systems to the Base case in scenario 1 could achieve NZEB and cover the school need of power by installing only PV with 20.4 efficiency to cover 90% of the rooftop area of baseline-school model. Thus, 100% of the school energy use could be offset with PV systems only. This scenario is the most cost-effective scenario based on the LCC analyses. This study scope was accounted for and future work in this area would focus on the following aspects:

- This study can be used as framework to evaluate the possibilities of achieving NZEB in other climatic conditions in Saudi Arabia.
- School buildings in the hot and humid climate regions. School located in this climate zone will have different factors and strategies due to higher energy consumptions Compared to school in mild climate.

- The impact of a broader measures should be studied.
- this research was limited by the lack of adequate local cost data, and more effort in the data collection from local manufactures and industry sources can increase the initial set of measures.
- future investigation can be conducted to include uncertainties of energy performance and costs of several measures studied in the analysis.
- Study can be extended to include for different passive and active systems. Systems like building orientation and forms, windows types, overhang devices, natural ventilations, Water Source Heat Pump etc.
- The procedure can be automated more by the use of available tools like RMI Website. This Excel-based tool is combatable with other simulation engines such as eQUEST and DesignBuilder and is capable for examining large numbers of factors.

Finally, reaching net zero energy is not just design matter; it needs careful consideration to operation and maintenance aspects, as well as to occupancy behavior and plug loads. This study reveals that net zero school building is possible with available technologies. this

Appendix A

The simulation results obtained by performing (246) base runs. the whole simulated scenarios results of this analysis

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
Abha NZEB School As-built model	134	0
Abha NZEB School Base model_ASHRAE 90.1-2010	136	2.25
WWR - Northern Walls_95% -- Window Shades - North_No change -- Window Glass Types - North_No change	138	3.64
WWR - Northern Walls_95% -- Window Shades - North_No change -- Window Glass Types - North_Sgl Clr	137	3.03
WWR - Northern Walls_95% -- Window Shades - North_No change -- Window Glass Types - North_Dbl Clr	137	2.53
WWR - Northern Walls_95% -- Window Shades - North_No change -- Window Glass Types - North_Dbl LoE	137	3.22
WWR - Northern Walls_95% -- Window Shades - North_No change -- Window Glass Types - North_Trp LoE	135	1.25
WWR - Northern Walls_95% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_No ch	136	1.61
WWR - Northern Walls_95% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Sgl C	135	1.28
WWR - Northern Walls_95% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Dbl C	135	1.19
WWR - Northern Walls_95% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Dbl L	136	1.61
WWR - Northern Walls_95% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Trp L	135	0.69
WWR - Northern Walls_95% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_No ch	135	0.78
WWR - Northern Walls_95% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Sgl C	135	0.56
WWR - Northern Walls_95% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Dbl C	135	0.56
WWR - Northern Walls_95% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Dbl L	135	0.92
WWR - Northern Walls_95% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Trp L	134	0.42
WWR - Northern Walls_65% -- Window Shades - North_No change -- Window Glass Types - North_No change	136	1.94
WWR - Northern Walls_65% -- Window Shades - North_No change -- Window Glass Types - North_Sgl Clr	136	1.56
WWR - Northern Walls_65% -- Window Shades - North_No change -- Window Glass Types - North_Dbl Clr	135	1.33
WWR - Northern Walls_65% -- Window Shades - North_No change -- Window Glass Types - North_Dbl LoE	136	1.72
WWR - Northern Walls_65% -- Window Shades - North_No change -- Window Glass Types - North_Trp LoE	135	0.72
WWR - Northern Walls_65% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_No ch	135	0.97
WWR - Northern Walls_65% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Sgl C	135	0.72
WWR - Northern Walls_65% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Dbl C	135	0.75
WWR - Northern Walls_65% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Dbl L	135	1.03
WWR - Northern Walls_65% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Trp L	135	0.50
WWR - Northern Walls_65% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_No ch	134	0.47
WWR - Northern Walls_65% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Sgl C	134	0.31
WWR - Northern Walls_65% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Dbl C	134	0.39
WWR - Northern Walls_65% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Dbl L	135	0.64
WWR - Northern Walls_65% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Trp L	134	0.31
WWR - Northern Walls_30% -- Window Shades - North_No change -- Window Glass Types - North_No change	135	0.53
WWR - Northern Walls_30% -- Window Shades - North_No change -- Window Glass Types - North_Sgl Clr	134	0.39

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
WWR - Northern Walls_30% -- Window Shades - North_No change -- Window Glass Types - North_Dbl Clr	134	0.44
WWR - Northern Walls_30% -- Window Shades - North_No change -- Window Glass Types - North_Dbl LoE	135	0.58
WWR - Northern Walls_30% -- Window Shades - North_No change -- Window Glass Types - North_Trp LoE	134	0.31
WWR - Northern Walls_30% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_No ch	134	0.33
WWR - Northern Walls_30% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Sgl C	134	0.25
WWR - Northern Walls_30% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Dbl C	134	0.31
WWR - Northern Walls_30% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Dbl L	134	0.44
WWR - Northern Walls_30% -- Window Shades - North_1/3 Win Height -- Window Glass Types - North_Trp L	134	0.22
WWR - Northern Walls_30% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_No ch	134	0.22
WWR - Northern Walls_30% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Sgl C	134	0.14
WWR - Northern Walls_30% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Dbl C	134	0.22
WWR - Northern Walls_30% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Dbl L	134	0.36
WWR - Northern Walls_30% -- Window Shades - North_2/3 Win Height -- Window Glass Types - North_Trp L	134	0.17
WWR - Northern Walls_0% -- Window Shades - North_No change -- Window Glass Types - North_No change	134	0.03
WWR - Southern Walls_95% -- Window Shades - South_No change -- Window Glass Types - South_No change	144	9.75
WWR - Southern Walls_95% -- Window Shades - South_No change -- Window Glass Types - South_Sgl Clr	143	8.53
WWR - Southern Walls_95% -- Window Shades - South_No change -- Window Glass Types - South_Dbl Clr	141	7.19
WWR - Southern Walls_95% -- Window Shades - South_No change -- Window Glass Types - South_Dbl LoE	142	8.42
WWR - Southern Walls_95% -- Window Shades - South_No change -- Window Glass Types - South_Trp LoE	137	3.00
WWR - Southern Walls_95% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_No ch	137	3.36
WWR - Southern Walls_95% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Sgl C	137	2.67
WWR - Southern Walls_95% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Dbl C	136	2.33
WWR - Southern Walls_95% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Dbl L	137	3.08
WWR - Southern Walls_95% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Trp L	135	0.67
WWR - Southern Walls_95% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_No ch	135	1.03
WWR - Southern Walls_95% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Sgl C	135	0.53
WWR - Southern Walls_95% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Dbl C	134	0.47
WWR - Southern Walls_95% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Dbl L	135	1.08
WWR - Southern Walls_95% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Trp L	134	-0.42
WWR - Southern Walls_65% -- Window Shades - South_No change -- Window Glass Types - South_No change	140	5.83
WWR - Southern Walls_65% -- Window Shades - South_No change -- Window Glass Types - South_Sgl Clr	139	4.94
WWR - Southern Walls_65% -- Window Shades - South_No change -- Window Glass Types - South_Dbl Clr	138	3.94
WWR - Southern Walls_65% -- Window Shades - South_No change -- Window Glass Types - South_Dbl LoE	139	4.69
WWR - Southern Walls_65% -- Window Shades - South_No change -- Window Glass Types - South_Trp LoE	135	1.28
WWR - Southern Walls_65% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_No ch	136	1.83
WWR - Southern Walls_65% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Sgl C	135	1.31
WWR - Southern Walls_65% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Dbl C	135	1.08
WWR - Southern Walls_65% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Dbl L	136	1.64
WWR - Southern Walls_65% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Trp L	134	-0.03

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
WWR - Southern Walls_65% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_No ch	134	0.25
WWR - Southern Walls_65% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Sgl C	134	-0.14
WWR - Southern Walls_65% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Dbl C	134	-0.14
WWR - Southern Walls_65% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Dbl L	134	0.31
WWR - Southern Walls_65% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Trp L	133	-0.78
WWR - Southern Walls_30% -- Window Shades - South_No change -- Window Glass Types - South_No change	135	1.36
WWR - Southern Walls_30% -- Window Shades - South_No change -- Window Glass Types - South_Sgl Clr	135	0.97
WWR - Southern Walls_30% -- Window Shades - South_No change -- Window Glass Types - South_Dbl Clr	135	0.58
WWR - Southern Walls_30% -- Window Shades - South_No change -- Window Glass Types - South_Dbl LoE	135	0.89
WWR - Southern Walls_30% -- Window Shades - South_No change -- Window Glass Types - South_Trp LoE	134	-0.42
WWR - Southern Walls_30% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_No ch	134	-0.06
WWR - Southern Walls_30% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Sgl C	134	-0.31
WWR - Southern Walls_30% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Dbl C	134	-0.39
WWR - Southern Walls_30% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Dbl L	134	-0.14
WWR - Southern Walls_30% -- Window Shades - South_1/3 Win Height -- Window Glass Types - South_Trp L	133	-0.94
WWR - Southern Walls_30% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_No ch	133	-0.78
WWR - Southern Walls_30% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Sgl C	133	-0.94
WWR - Southern Walls_30% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Dbl C	133	-0.94
WWR - Southern Walls_30% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Dbl L	133	-0.75
WWR - Southern Walls_30% -- Window Shades - South_2/3 Win Height -- Window Glass Types - South_Trp L	133	-1.28
WWR - Southern Walls_0% -- Window Shades - South_No change -- Window Glass Types - South_No change	132	-1.69
WWR - Western Walls_95% -- Window Shades - West_No change -- Window Glass Types - West_No change	146	12.31
WWR - Western Walls_95% -- Window Shades - West_No change -- Window Glass Types - West_Sgl Clr	145	11.31
WWR - Western Walls_95% -- Window Shades - West_No change -- Window Glass Types - West_Dbl Clr	144	10.17
WWR - Western Walls_95% -- Window Shades - West_No change -- Window Glass Types - West_Dbl LoE	146	11.64
WWR - Western Walls_95% -- Window Shades - West_No change -- Window Glass Types - West_Trp LoE	139	5.25
WWR - Western Walls_95% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_No chang	141	7.28
WWR - Western Walls_95% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Sgl Clr	140	6.33
WWR - Western Walls_95% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Dbl Clr	140	6.19
WWR - Western Walls_95% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Dbl LoE	141	6.92
WWR - Western Walls_95% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Trp LoE	137	2.89
WWR - Western Walls_95% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_No chang	138	3.81
WWR - Western Walls_95% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Sgl Clr	137	3.19
WWR - Western Walls_95% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Dbl Clr	137	3.44
WWR - Western Walls_95% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Dbl LoE	138	3.89
WWR - Western Walls_95% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Trp LoE	135	1.25
WWR - Western Walls_65% -- Window Shades - West_No change -- Window Glass Types - West_No change	142	7.83
WWR - Western Walls_65% -- Window Shades - West_No change -- Window Glass Types - West_Sgl Clr	141	7.11

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
WWR - Western Walls_65% -- Window Shades - West_No change -- Window Glass Types - West_Dbl Clr	140	6.22
WWR - Western Walls_65% -- Window Shades - West_No change -- Window Glass Types - West_Dbl LoE	141	7.19
WWR - Western Walls_65% -- Window Shades - West_No change -- Window Glass Types - West_Trp LoE	137	2.69
WWR - Western Walls_65% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_No chang	138	4.14
WWR - Western Walls_65% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Sgl Clr	138	3.89
WWR - Western Walls_65% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Dbl Clr	138	3.69
WWR - Western Walls_65% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Dbl LoE	138	4.22
WWR - Western Walls_65% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Trp LoE	135	1.22
WWR - Western Walls_65% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_No chang	136	1.81
WWR - Western Walls_65% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Sgl Clr	136	1.78
WWR - Western Walls_65% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Dbl Clr	136	1.92
WWR - Western Walls_65% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Dbl LoE	136	2.19
WWR - Western Walls_65% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Trp LoE	134	0.25
WWR - Western Walls_30% -- Window Shades - West_No change -- Window Glass Types - West_No change	136	2.25
WWR - Western Walls_30% -- Window Shades - West_No change -- Window Glass Types - West_Sgl Clr	136	1.78
WWR - Western Walls_30% -- Window Shades - West_No change -- Window Glass Types - West_Dbl Clr	135	1.33
WWR - Western Walls_30% -- Window Shades - West_No change -- Window Glass Types - West_Dbl LoE	136	1.75
WWR - Western Walls_30% -- Window Shades - West_No change -- Window Glass Types - West_Trp LoE	134	0.06
WWR - Western Walls_30% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_No chang	135	0.92
WWR - Western Walls_30% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Sgl Clr	135	0.58
WWR - Western Walls_30% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Dbl Clr	134	0.42
WWR - Western Walls_30% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Dbl LoE	135	0.72
WWR - Western Walls_30% -- Window Shades - West_1/3 Win Height -- Window Glass Types - West_Trp LoE	134	-0.39
WWR - Western Walls_30% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_No chang	134	0.11
WWR - Western Walls_30% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Sgl Clr	134	-0.11
WWR - Western Walls_30% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Dbl Clr	134	-0.14
WWR - Western Walls_30% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Dbl LoE	134	0.11
WWR - Western Walls_30% -- Window Shades - West_2/3 Win Height -- Window Glass Types - West_Trp LoE	133	-0.67
WWR - Western Walls_0% -- Window Shades - West_No change -- Window Glass Types - West_No change	133	-1.44
WWR - Eastern Walls_95% -- Window Shades - East_No change -- Window Glass Types - East_No change	144	9.75
WWR - Eastern Walls_95% -- Window Shades - East_No change -- Window Glass Types - East_Sgl Clr	143	8.56
WWR - Eastern Walls_95% -- Window Shades - East_No change -- Window Glass Types - East_Dbl Clr	142	7.86
WWR - Eastern Walls_95% -- Window Shades - East_No change -- Window Glass Types - East_Dbl LoE	143	9.11
WWR - Eastern Walls_95% -- Window Shades - East_No change -- Window Glass Types - East_Trp LoE	138	3.97
WWR - Eastern Walls_95% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_No chang	139	4.75
WWR - Eastern Walls_95% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Sgl Clr	138	4.03
WWR - Eastern Walls_95% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Dbl Clr	138	3.94
WWR - Eastern Walls_95% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Dbl LoE	139	4.83

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
WWR - Eastern Walls_95% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Trp LoE	136	1.83
WWR - Eastern Walls_95% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_No chang	136	1.92
WWR - Eastern Walls_95% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Sgl Clr	135	1.44
WWR - Eastern Walls_95% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Dbl Clr	136	1.58
WWR - Eastern Walls_95% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Dbl LoE	136	2.28
WWR - Eastern Walls_95% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Trp LoE	135	0.56
WWR - Eastern Walls_65% -- Window Shades - East_No change -- Window Glass Types - East_No change	140	6.03
WWR - Eastern Walls_65% -- Window Shades - East_No change -- Window Glass Types - East_Sgl Clr	139	5.22
WWR - Eastern Walls_65% -- Window Shades - East_No change -- Window Glass Types - East_Dbl Clr	139	4.69
WWR - Eastern Walls_65% -- Window Shades - East_No change -- Window Glass Types - East_Dbl LoE	139	5.44
WWR - Eastern Walls_65% -- Window Shades - East_No change -- Window Glass Types - East_Trp LoE	136	2.14
WWR - Eastern Walls_65% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_No chang	137	2.94
WWR - Eastern Walls_65% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Sgl Clr	136	2.44
WWR - Eastern Walls_65% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Dbl Clr	136	2.33
WWR - Eastern Walls_65% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Dbl LoE	137	2.92
WWR - Eastern Walls_65% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Trp LoE	135	0.92
WWR - Eastern Walls_65% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_No chang	135	1.22
WWR - Eastern Walls_65% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Sgl Clr	135	0.89
WWR - Eastern Walls_65% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Dbl Clr	135	0.89
WWR - Eastern Walls_65% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Dbl LoE	135	1.36
WWR - Eastern Walls_65% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Trp LoE	134	0.14
WWR - Eastern Walls_30% -- Window Shades - East_No change -- Window Glass Types - East_No change	136	1.89
WWR - Eastern Walls_30% -- Window Shades - East_No change -- Window Glass Types - East_Sgl Clr	136	1.56
WWR - Eastern Walls_30% -- Window Shades - East_No change -- Window Glass Types - East_Dbl Clr	135	1.25
WWR - Eastern Walls_30% -- Window Shades - East_No change -- Window Glass Types - East_Dbl LoE	136	1.58
WWR - Eastern Walls_30% -- Window Shades - East_No change -- Window Glass Types - East_Trp LoE	134	0.31
WWR - Eastern Walls_30% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_No chang	135	0.81
WWR - Eastern Walls_30% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Sgl Clr	135	0.58
WWR - Eastern Walls_30% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Dbl Clr	135	0.50
WWR - Eastern Walls_30% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Dbl LoE	135	0.72
WWR - Eastern Walls_30% -- Window Shades - East_1/3 Win Height -- Window Glass Types - East_Trp LoE	134	-0.08
WWR - Eastern Walls_30% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_No chang	134	0.17
WWR - Eastern Walls_30% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Sgl Clr	134	0.00
WWR - Eastern Walls_30% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Dbl Clr	134	0.00
WWR - Eastern Walls_30% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Dbl LoE	134	0.19
WWR - Eastern Walls_30% -- Window Shades - East_2/3 Win Height -- Window Glass Types - East_Trp LoE	134	-0.36
WWR - Eastern Walls_0% -- Window Shades - East_No change -- Window Glass Types - East_No change	133	-0.86
Building Orientation (Degrees)_0	134	0.31
Building Orientation (Degrees)_45	134	0.42

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
Building Orientation (Degrees)_90	134	0.25
Building Orientation (Degrees)_135	134	-0.14
Building Orientation (Degrees)_180	134	0.06
Building Orientation (Degrees)_225	134	0.39
Building Orientation (Degrees)_270	135	0.58
Building Orientation (Degrees)_315	134	0.36
Wall Construction_Uninsulated	134	0.47
Wall Construction_R13 Metal	135	0.78
Wall Construction_R13 Wood	135	1.33
Wall Construction_R13+R10 Metal	135	0.94
Wall Construction_14-inch ICF	135	1.00
Wall Construction_R38 Wood	135	1.25
Wall Construction_R2 CMU	134	0.11
Wall Construction_12.25-inch SIP	135	1.25
Roof Construction_Uninsulated	141	6.78
Roof Construction_R10	135	1.17
Roof Construction_R19	135	1.08
Roof Construction_R38	135	0.72
Roof Construction_R60	135	0.61
Roof Construction_10.25-inch SIP	135	0.72
Roof Construction_R15	135	0.86
Infiltration (ACH)_0.17 ACH	135	0.64
Infiltration (ACH)_0.4 ACH	134	0.31
Infiltration (ACH)_0.8 ACH	134	-0.17
Infiltration (ACH)_1.2 ACH	133	-0.56
Infiltration (ACH)_1.6 ACH	133	-0.86
Infiltration (ACH)_2.0 ACH	133	-1.06
Lighting Efficiency_0.3 W/sf	100	-34.06
Lighting Efficiency_0.7 W/sf	118	-16.36
Lighting Efficiency_1.1 W/sf	135	1.44
Lighting Efficiency_1.5 W/sf	153	19.36
Lighting Efficiency_1.9 W/sf	171	37.47
Daylighting & Occupancy Contro_None	134	0.31
Daylighting & Occupancy Contro_Daylighting Controls	132	-2.42
Daylighting & Occupancy Contro_Occupancy Controls	128	-6.22
Daylighting & Occupancy Contro_Daylighting & Occupancy Contro	125	-8.56
Plug Load Efficiency_0.6 W/sf	130	-4.44
Plug Load Efficiency_1.0 W/sf	150	15.81
Plug Load Efficiency_1.3 W/sf	165	31.08

Base Run	EUI (kWh / m² / yr)	EUI ± (kWh)
Plug Load Efficiency_1.6 W/sf	180	46.47
Plug Load Efficiency_2.0 W/sf	201	67.00
Plug Load Efficiency_2.6 W/sf	232	97.92
HVAC Types_ASHRAE Package System	133	-0.86
HVAC Types_High Eff. Heat Pump	124	-10.47
HVAC Types_ASHRAE Heat Pump	136	1.78
HVAC Types_High Eff. Package System	127	-7.47
HVAC Types_High Eff. VAV	121	-13.19
HVAC Types_ASHRAE Package Terminal Heat P	121	-13.08
HVAC Types_High Eff. Package Terminal AC	128	-5.64
Operating Schedule_24/7	231	97.11
Operating Schedule_12/7	180	46.36
Operating Schedule_12/6	163	29.03
Operating Schedule_12/5	140	6.08
Min / Max Internal Loads_Max Internal Loads	267	133.36
Min / Max Internal Loads_Min Internal Loads	93	-40.89
Min / Max Envelope_Max Envelope	141	7.33
Min / Max Envelope_Min Envelope	136	1.64
Min / Max Form_Max Form	164	29.58
Min / Max Form_Min Form	129	-4.94

Appendix B

Lighting Power Incremental Cost calculations

Description	Qty	Unit	Baseline case Rate US $	Baseline case Total Amount $ US	LED Alternatives Rate US $	LED Alternatives Total Amount $ US
Supply and install 2X40W ceiling fluorescent lamp with Reflective for corridors	68	Nos.	37.8	2570.4	45.8	3114.4
Supply and install 2X40W ceiling fluorescent lamp with cap	14	Nos.	54	756	62	868
Supply and install 3X40W ceiling fluorescent lamp with cap for staff rooms	204	Nos.	54	11016	66	13464
Supply and install wall mounting lighting luminary with lamp 100w	3	Nos.	27	81	41	123
Supply and install cylindrical metal headed bulb unit	10	Nos.	129.6	1296	190	1900
Supply and install Wall lighting unit with semi-conical lid and 100 watts	4	Nos.	86.4	345.6	95	380
Supply and install semicircular lighting unit with a 100W incandescent luminaire for entrances and stairs	16	Nos.	27	432	45	720
Total	**319**			**16497**		**20569.4**
					Incremental Cost	**$ 4072.4**

Air Conditioning Incremental Cost calculations

Description	Qty	Unit	Baseline case Rate US $	Baseline case Total Amount $ US	LED Alternatives Rate US $	LED Alternatives Total Amount $ US
Supply and installation split air conditioner (hot / cold) capacity 18000 BTU	66	Nos.	1215	80190	1600	105600
Supply and installation split air conditioner (hot / cold) capacity 24000 BTU	14	Nos.	1485	20790	1900	26600
total				100980		132200
					Incremental Cost	**$31220**

Appendix C

Interest and Annuity Tables for Discrete Compounding

TABLE C-9 Discrete Compounding; $i = 6\%$

	Single Payment		Uniform Series				Uniform Gradient		
	Compound Amount Factor	Present Worth Factor	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Gradient Present Worth Factor	Gradient Uniform Series Factor	
	To Find F Given P	To Find P Given F	To Find F Given A	To Find P Given A	To Find A Given F	To Find A Given P	To Find P Given G	To Find A Given G	
N	F/P	P/F	F/A	P/A	A/F	A/P	P/G	A/G	N
1	1.0600	0.9434	1.0000	0.9434	1.0000	1.0600	0.000	0.0000	1
2	1.1236	0.8900	2.0600	1.8334	0.4854	0.5454	0.890	0.4854	2
3	1.1910	0.8396	3.1836	2.6730	0.3141	0.3741	2.569	0.9612	3
4	1.2625	0.7921	4.3746	3.4651	0.2286	0.2886	4.946	1.4272	4
5	1.3382	0.7473	5.6371	4.2124	0.1774	0.2374	7.935	1.8836	5
6	1.4185	0.7050	6.9753	4.9173	0.1434	0.2034	11.459	2.3304	6
7	1.5036	0.6651	8.3938	5.5824	0.1191	0.1791	15.450	2.7676	7
8	1.5938	0.6274	9.8975	6.2098	0.1010	0.1610	19.842	3.1952	8
9	1.6895	0.5919	11.4913	6.8017	0.0870	0.1470	24.577	3.6133	9
10	1.7908	0.5584	13.1808	7.3601	0.0759	0.1359	29.602	4.0220	10
11	1.8983	0.5268	14.9716	7.8869	0.0668	0.1268	34.870	4.4213	11
12	2.0122	0.4970	16.8699	8.3838	0.0593	0.1193	40.337	4.8113	12
13	2.1329	0.4688	18.8821	8.8527	0.0530	0.1130	45.963	5.1920	13
14	2.2609	0.4423	21.0151	9.2950	0.0476	0.1076	51.713	5.5635	14
15	2.3966	0.4173	23.2760	9.7122	0.0430	0.1030	57.555	5.9260	15
16	2.5404	0.3936	25.6725	10.1059	0.0390	0.0990	63.459	6.2794	16
17	2.6928	0.3714	28.2129	10.4773	0.0354	0.0954	69.401	6.6240	17
18	2.8543	0.3503	30.9057	10.8276	0.0324	0.0924	75.357	6.9597	18
19	3.0256	0.3305	33.7600	11.1581	0.0296	0.0896	81.306	7.2867	19
20	3.2071	0.3118	36.7856	11.4699	0.0272	0.0872	87.230	7.6051	20
21	3.3996	0.2942	39.9927	11.7641	0.0250	0.0850	93.114	7.9151	21
22	3.6035	0.2775	43.3923	12.0416	0.0230	0.0830	98.941	8.2166	22
23	3.8197	0.2618	46.9958	12.3034	0.0213	0.0813	104.701	8.5099	23
24	4.0489	0.2470	50.8156	12.5504	0.0197	0.0797	110.381	8.7951	24
25	4.2919	0.2330	54.8645	12.7834	0.0182	0.0782	115.973	9.0722	25
30	5.7435	0.1741	79.0582	13.7648	0.0126	0.0726	142.359	10.3422	30
35	7.6861	0.1301	111.4348	14.4982	0.0090	0.0690	165.743	11.4319	35
40	10.2857	0.0972	154.7620	15.0463	0.0065	0.0665	185.957	12.3590	40
45	13.7646	0.0727	212.7435	15.4558	0.0047	0.0647	203.110	13.1413	45
50	18.4202	0.0543	290.3359	15.7619	0.0034	0.0634	217.457	13.7964	50
60	32.9877	0.0303	533.1282	16.1614	0.0019	0.0619	239.043	14.7909	60
80	105.7960	0.0095	1746.5999	16.5091	0.0006	0.0606	262.549	15.9033	80
100	339.3021	0.0029	5638.3681	16.6175	0.0002	0.0602	272.047	16.3711	100
∞				16.6667		0.0600			∞

References

[1] ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Guideline 14 2002, Measurement of Energy and Demand and Savings, ISSN 1049-894X, 2002, Atlanta, GA, U.S.

[2] ASHRAE/ARI/ISO Standard 13256-1:1998 (R2012)

[3] Branker, K., Pathak, M. J. M., & Pearce, Joshua M. (2011). A review of solar photovoltaic levelized cost of electricity. Renewable and Sustainable Energy Reviews, 15(9), 4470-4482. http://digitalcommons.mtu.edu/materials_fp/28/

[4] Building Performance Analysis in Revit 2016 R2 with Autodesk Insight 360 at http://www.aecbytes.com/tipsandtricks/2015/issue76-revit.html

[5] Butala, V. and P. Novak (1999). "Energy consumption and potential energy savings in old school buildings." Energy and buildings 29(3): 241-246.

[6] Crawley, D. B., Lawrie, L. K., Winkelmann, F. C., Buhl, W. F., Huang, Y. J., Pedersen, C. O., Strand, R. K., Liesen, R. J., Fisher, D. E., Witte, M. J., et al., 2001, Energyplus: creating a new-generation building energy simulation program". Energy and buildings, 33(4), pp. 319-331.

[7] Demographic Survey 2016 _General Authority for Statistics, Riyadh, SA.

[8] Department of Energy, 2015, Building energy software tools directory. On the WWW, Retrieved March 2015. URL http://goo.gl/Jmfu6y.

[9] Department of Energy. 2018. "Advanced energy design guide for K-12 school buildings: Achieving Zero Energy." Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. at www.ashrae.org/publicationupdates.

[10] Desideri, U. and S. Proietti (2002). "Analysis of energy consumption in the high schools of a province in central Italy." Energy and Buildings 34(10): 1003-1016.

[11] Dickson, A., B. Garvey and M. Larson (2007). "Green energy options for sustainable local economic development: Policy, Financing and Strategies for Green Energy." Georgia institute of technology.

[12] DOE-2, 2009, eQUEST - the quick energy simulation tool. On the WWW, Retrieved March 2015. URL http://goo.gl/3rTEkf

[13] Dutil, Y., D. Rousse and G. Quesada (2011). "Sustainable buildings: An ever-evolving target." Sustainability 3(2): 443-464.

[14] ECRA,2015 "Annual Statistical Booklet for Electricity and Seawater Desalination Industries" Electricity and Cogeneration Regulatory Authority, Riyadh, SA.

[15] EIA, U. (2009)."Annual energy review 2009." US Energy Information administration, Washington, DC.

[16] EIA, U. (2012). Annual energy review 2012." US Energy Information administration, Washington, DC.

[17] Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2018, Annual Supplement to NIST Handbook 135 at, https://nvlpubs.nist.gov/nistpubs/ir/2018/NIST.IR.85-3273-33.pdf

[18] EPA. 2018. ENERGY STAR Products. U.S. Environmental Protection Agency. Washington, D.C. Last accessed in March, 2018 at: http://www.energystar.gov/index.cfm?fuseaction=find_a_product

[19] Fu, R., D. Chung. T. Lowder, D. Feldman, K. Ardani, and R. Margolis. U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy16osti/66532.pdf

[20] Gluch, P. and H. Baumann (2004). "The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making." Building and environment 39(5): 571-580.

[21] Griffith, B, N. Long, P. Torcellini, R. Judkoff, D. Crawley, D. and J. Ryan. 2007. Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector. TP-550-41957, National Renewable Energy Laboratory, Golden, Colorado.

[22] Henninger, R. H., and Witte, M. J., 2014, EnergyPlus Testing with HERS BESTEST Tests from ANSI/ASHRAE Standard 140-2011. On the WWW, Retrieved 25th Feb 2015. URL https://goo.gl/O8OK79.

[23] Hutton, P. C. 2011. “Zero Energy Schools–Beyond Platinum.” Educational Facility Planner 45(3):43-46. Nbi new building institute. 2014. “Getting to Zero 2014 Status Update: A look at the projects, policies and programs driving zero net energy performance in comercial buildings.” http://newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.pdf

[24] IEA. 2016. Snapshots of global photovoltaic markets. Paris: International Energy Agency. www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2016__1_.pdf

[25] Kansal, R., & Kadambari, G. (2010). Green buildings: An assessment of life cycle cost. IUP Journal of Infrastructure, 8(4), 50-57.

[26] Klein, S. A., 1979, TRNSYS, a transient system simulation program. Solar Energy Laboratory, University of Wisconsin {Madison.

[27] Kolokotsa, D., D. Rovas, E. Kosmatopoulos and K. Kalaitzakis (2011). "A roadmap towards intelligent net zero-and positive-energy buildings." Solar Energy 85(12): 3067-3084.

[28] Langston, C. A. and G. K. Ding (2001). Sustainable Practices: Development and Construction in an Environmental Age, Butterworth Heinemann: London.

[29] Lemire, N. (2010). "School and more." ASHRAE Journal 52(5).

[30] M. K. Le, "Autodesk Green Building Studio for An Energy-Efficient, Sustainable Building,", pp. 10, 2014

[31] Maile, T., Fischer, M., and Bazjanac, V., 2007, Building energy performance simulation tools - a life-cycle and interoperable perspective".

[32] Means, R., 2011, Green building: Project planning and cost estimating, Vol. 73. John Wiley & Sons.

[33] Morris, M.D. (1991). Factorial Sampling Plans for Preliminary Computational Experiments, Technimetrics, Vol. 33, No. 2, pp. 161-174.

[34] Morrow, W. R., K. S. Gallagher, G. Collantes and H. Lee (2010). "Analysis of policies to reduce oil consumption and greenhouse-gas emissions from the US transportation sector." Energy Policy 38(3): 1305-1320.

[35] National Aeronautics and Space Administration(NASA), https://earthdata.nasa.gov/

[36] New York State Energy Research and Development Authority, Net Zero Energy Housing at, https://www.nyserda.ny.gov/net-zero

[37] NIST. 1995. Life-Cycle Costing Manual for the Federal Energy Management Program. NIST Handbook 135, U.S. Department of Commerce, Technology Administration, Washington, D.C., and National Institute of Standards and Technology, Gaithersburg, MD.

[38] Office Of Energy Efficiency & Renewable Energy

[39] Pasqualetto, L.; Zmeureantu, R.; Fazio, P. 1997. "A Case Study of Validation of an Energy Analysis Program: MICRO-DOE-2.1E." Building and Environment, Vol. 33, No. 1, June 1997; pp. 21–41.

[40] REN21. RENEWABLES 2014 GLOBAL STATUS REPORT.2014 Available: http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf.

[41] Rwelamila Strand, T., L. Mrig, R. Hansen and K. Emery (1996). "Technical evaluation of a dual junction same-band-gap amorphous silicon photovoltaic system." Solar energy materials and solar cells 41: 617-628.

[42] Sanchez, D.G., Carrier, B., & Bourges, B. (2014). Application of sensitivity analysis in building energy simulations: Combining first and second order elementary effects methods, Energy and Buildings 68, 741-750.

[43] Standards of California Energy Commission 2005 Building Energy Efficiency; Nonresidential Alternative Calculation Method (ACM) Manual, Table N2-2.

[44] Steurer, R. and M. Hametner (2013). "Objectives and indicators in sustainable development strategies: similarities and variances across Europe." Sustainable Development 21(4): 224-241.

[45] Thermal Energy System Specialists, 2008. TRNSYS Overview. On the WWW, Retrieved 26th Feb 2015. URL http://tess-inc.com/trnsys.

[46] Thornton, B., Halverson, M., Myer, M., Cho, H., Loper, S., Richman, E., Elliott, D., Mendon, V., & Rosenberg, M. (2013). Cost-Effectiveness of ASHRAE Standard 90.1- 2010 Compared to ASHRAE Standard 90.1-2007. PNNL-22972, Pacific Northwest National Laboratory, Richland, WA.

[47] Torcellini, P. A., S. Pless, M. Deru, B. Griffith, N. Long and R. Judkoff (2006). Lessons learned from case studies of six high-performance buildings. National Renewable Energy Laboratory Golden, Colorado.

[48] U.S Department of State, 2014, U.S. climate action report to the unframe work convention on climate change. On the WWW, Retrieved Feb. 2015. URL http://go.usa.gov/dpa3.

[49] U.S. Department of Energy, Federal Energy Management Program (FEMP).M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 4.0, 2015.

[50] Yang, L., J. C. Lam and C. L. Tsang (2008). "Energy performance of building envelopes in different climate zones in China." Applied Energy 85(9): 800-817.

[51] Zhu, D., 2014, Comparison of building energy modeling programs: Building loads".

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